2-DAY CONFERENCE ON
"METALLURGY IN POWER SECTOR & INDUSTRIES"

VADODARA ON 29 (THU) & 30 (FRI) SEP 2022

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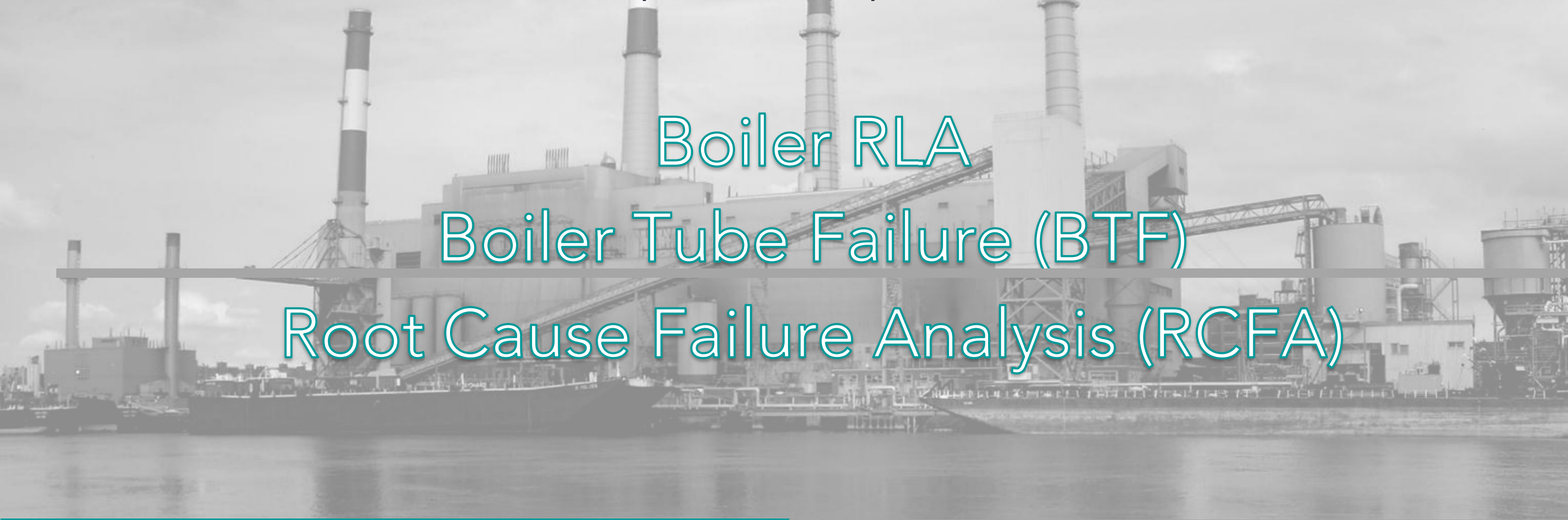

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FORM XVI-H
[see regulation 4C]

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IMPORTANCE OF MATERIALS & METALLURGY IN HYDRO POWER EQUIPMENT AND RELEVANT CASE STUDIES

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ABSTRACT:

Hydro Power Sector is currently experiencing advance technological developments. New materials & metallurgy are emerging to make hydro industry more & more dynamic and sustainable. Hydro equipment require various type of materials and their metallurgy for specific applications. However, metallurgical background is not available with the designers hence it is a significant gap between the design requirement and location wise plant /environmental requirement. The silt erosion, cavitations and corrosion continues to be an unresolved issue being faced by many hydro power stations specially located in Himalayan terrain, run-of-the- river projects or in Northern Indian hydro projects. Development in the areas of control of silt erosion from reaching the turbine and erosion resistance steel, protective coating has been the main focus of R&D. However, material considerations are limited which can also increase the performance, durability, reliability and availability of hydro machines if their metallurgy is well optimized. Damages concerning water components and turbines are caused mainly by corrosive wear, silt erosion, cavitation problems, materials & metallurgical defects and fatigue. Damage problems occur primarily in turbine under water for higher heads than above 250M. This problem accelerated when the silt-laden water passes through the turbine and damage takes place in even lower head power plants. To cope with these problems, the various studies on the properties of materials have been carried out and are going on. The importance of metallurgy and their advantages, limitations, & performances are discussed and presented in this paper. Two case studies i.e., 1) Tashiding Runner and 2) Dikshi Labyrinth with their metallurgy and its impact on their performance are discussed.

Key Words: Hydro, Materials, Turbine Metallurgy, Silt Erosion, Protective Technologies, Turbine Damages.

1.0 INTRODUCTION:

Hydro power is a renewable source of energy that converts the waterpower to wire through the rotation of a turbine via generator. Several emerging hydro power technologies including materials & metallurgy are underway which can play an important role. The materials can be categorized into the different categories such as materials for turbines, dams / waterways, bearings, seals etc. The various grade of materials & protective materials which are in use and could be used in Hydro are shown below in Fig.1.

Materials: Austenitic stainless-steel grades, Martensitic Stainless Steel, Duplex Stainless steel, and Super martensitic stainless steel.

Welding: Stellate, WC for runner blades with CA-6NM and WC with WC etc in addition to the similar grade of base materials.

Coatings: Diamond like carbon coating by diffusion process and Super Hard Coatings (SHC).

These coatings are very very hard (> 49 Gpa comparative to 3 Gpa for stainless steel) and tough and extremely erosion resistance nano composite coatings, Conventional HVOF coating, HP-HVOF Coating, Plasma Coatings.

Fig.1. Hydro turbine appearance and role of metallurgy can be seen here a) Pelton Turbine and b) Francis Turbine.

Major challenges in hydro power plants are sediment issue especially in the Himalayan region which damages most of the hydro components. The efficient settling and flushing of silt discharge excessive sediment into the river intermittently, causes turbine damages. These damages of turbine component in addition to materials & metallurgy characteristics, depend on: (i) eroding particles - size, shape, hardness, (ii) substrates – chemistry, elastic properties, surface hardness, surface morphology, and (iii) operating conditions – velocity, impingement angle, and concentration. Depending on the gradient of the river and distance traversed by the sand particles, the shape and size of sediment particles vary at different locations of the same river system, where little metallurgical chemical changes is very helpful to gain required properties which can minimise the hydro damages. Below Fig.2(a-e) shows the turbine erosion and silt particle damages in ***Himalayan Power Plant*** on Francis and Pelton turbine (fig.2a &b). Fig.2c shows the severity of erosion damages such as ***Cobra Erosion*** with its resemblance hence its termed as Cobra Erosion damages, by the author which is now popularly known as ***Cobra Erosion***. Fig.2e shows the ***Orange Peel*** surface of eroded bucket.

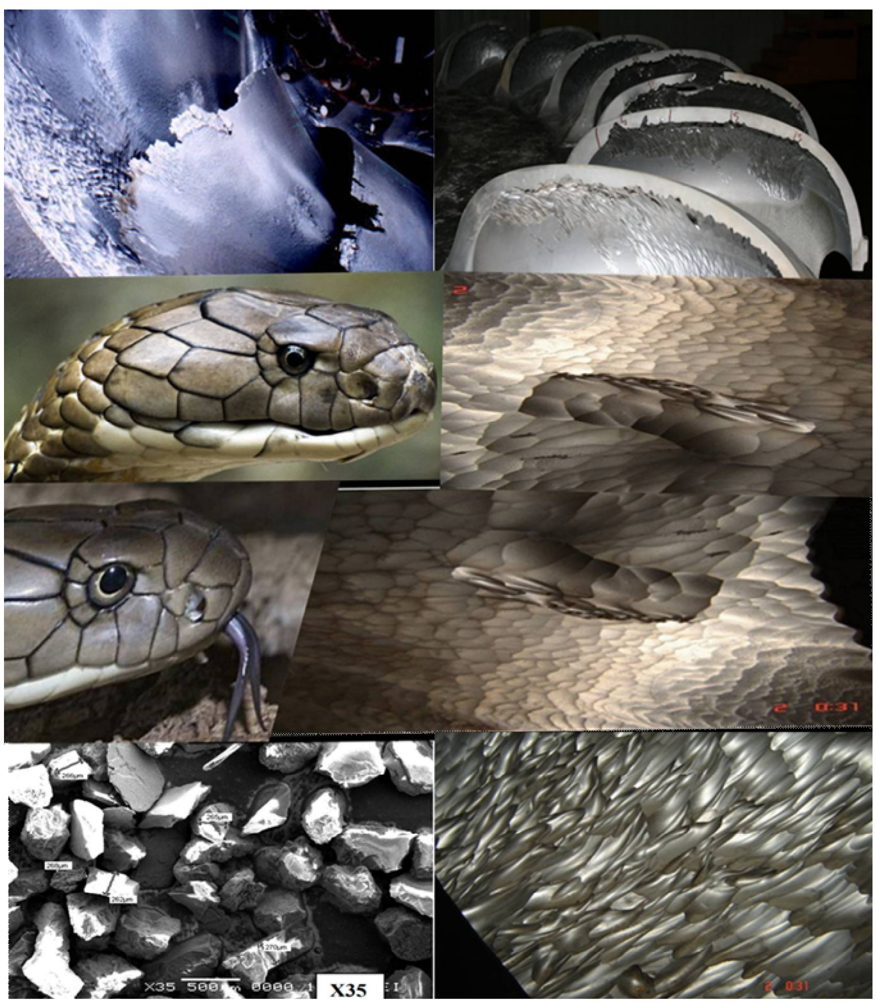

Fig.2: Hydro Turbine Damage due to Silt a) Francis Turbine, b) Pelton Turbine, c) Cobra Erosion, d) Silt consisting 93% quartz & e) its impact on turbine as cobra damages on surface can be seen.

MATERIALS & METALLURGY FOR HYDRO TURBINES AND EQUIPMENT

The materials commonly used globally for hydro turbines are ***Austenitic and Martensitic Stainless Steel*** with Cr-12% to 20% & Ni-0.5 to 10.5% to improve the stability of the protective film and a longer life span of the runner blades. Today, the blades are mostly made of *Martensitic SS,* whose strength is twice that of Austenitic SS. Generally, the turbines employed for high-head applications must be made with materials resistance to high stresses generated by the water pressure and fatigue, abrasion / erosion, and cavitations. Commonly selection of materials base is to reduce their weight and resistance to abrasion and fatigue. As mentioned above, these materials can also ensure a longer life span of hydro equipment by limiting the effects of cavitation, erosion, corrosion, and fatigue. Cavitation occurs owing to the formation of voids and bubbles, where the pressure of the liquid changes rapidly. Silt erosion damages components by the collision of particles on the material. Fatigue is the process of repeated cyclic stress, for example, during load variations and vibrations. The hydropower industry is also affected by biofouling /MIC corrosion. Corrosion is the combined effect of oxygen and air, and it can be minimized using novel materials instead of steel.

Stainless steels are complex alloys containing primarily **Cr & Ni** and other minor elements such as **Mo, Mn, C, N, and Ti.** The effect of these alloying elements are described in below section. In last decade, novel materials have been introduced such as a) Coating layers to better resist erosion, corrosion, and cavitation, and to reduce friction/ head losses b) structural materials to better resist loads and reduce weight. Coatings (HVOF/ Plasma) are also important for resisting cavitation and abrasion especially in waters with high sediment loads. Coatings can be mainly classified into ***hard coatings*** such as layers of oxides, carbides, and nitrides, ***Soft coatings*** (non-metallic) layers such as polyurethane, epoxy, nylon, and composite cermet coatings of hard reinforcements in tough matrix materials. The use of a coating layer of 13Cr4Ni steel for refinement led to a 2.6 times improvement in micro-hardness. The coatings for waterways **(e.g., penstocks)** reduce surface friction and consequently increase electricity generation. An additional example of material for penstock is of steel of high tensile steel (950 $N \cdot mm^{-2}$). However, brittle fracture may arise, and welding is critical for the inclusion of micro-fissures. **TABLE-1**

Typical Chemical & Mechanical Properties of SS Used in Hydro Industry

Material	C	Mn	Si	Cr	Ni	P	S	Mo
13/4 CrNi	0.06 Max	1.00 Max	1.00 Max	11.5-14.0	3.5-4.5	0.04 Max	0.04 Max	0.4-1.0
SS 410	0.15 Max	1.0 Max	1.0 Max	11.5-13.5	0.5 Max	0.04 Max	0.03 max	-
SS 415	0.05	0.5-1.0	0.60	11.0-14.0	3.5-5.5	0.03 max	0.03 max	0.5-1.0
18Cr/8	0.08	2.0	0.75	17.5-19.5	8.0-10.5	0.045	0.03	N~0.1
SS 420	0.15	1.0	1.0	12-14	-	0.04	0.03	-

Stainless Steel	Typical Annealed Properties			Hardenin	Impact -
	0.2% YS-MPa	TS - MPa	% EL in 2"	BHN	CVN
13/4 SS	520	700-850	>15	240-320	>70
Alloy 410	290	510	34	353-390	~
Alloy 415	520	700-800	15 Min.	220-250	~
18 Cr/8Ni	≥ 310	≥ 620	≥ 30	201	~
SS 420	>700	900	17	260	>60

3.1 CASE STUDIY 1 - Tashiding

Tashiding runner has been studies for its cracking and damages as discussed here. Tashiding is a 97MW (2 x 48.5 MW) *hydro power* project (Signed off in 2008), located on Rathang Chu river, a tributary of Rangit River basin in Sikkim, India. It has two Francis units of 48.5MW each. All components of the Project are laid out on the right bank of the River.

The main components of the Project are:

- A 40.25M long barrage with 4 Nos. of spillway bays and Intake located on the right bank of the river upstream of the barrage.
- 5.7kM long HRT of dia. 5.0M D-shaped concrete lined and Three number of construction adits of 6.0M D-Shape to facilitate construction of HRT.
- 234M long pressure shaft of 3.8M diameter followed by 282M long surface penstock leading to surface power house. Surface power house located on the right bank of the river equipped with 2 nos. of vertical axis Francis turbines, each rated at 48.5MW.

Visual Examination:

The visual examination of blades shows vertical cracks on bottom ring and erosion damages near to blade weld (figs.3-4). Blades looks like faced a either sever stresses due to welding or some metallurgical imbalances in the phases. Thickness of ring is reduced due to abrasion/erosion as can be seen. All the cracks were observed in two locations; **a)** Either just below the blade welding or **b)** Nearby welding area at the distance of 2-4 inch either side of the blade as seen in figs. 3-4.

Fig.3: Francis Turbine Damage due to cracking and erosion.

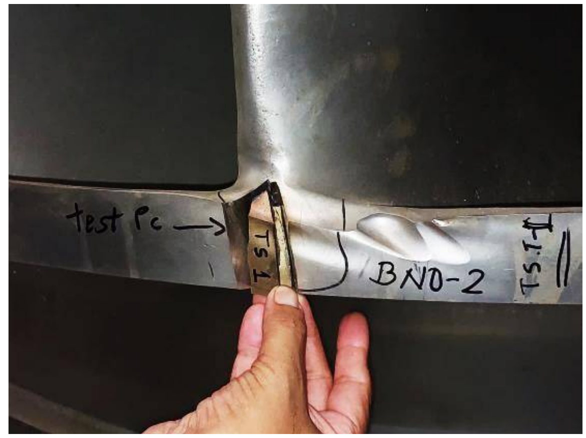

Fig.4: Francis Turbine Blade no.2 Damage due to cracking & erosion

a) Chemical Analysis:

The turbine metallurgy is studied for their chemical analysis as shown in table.1.1, hardness measurements and microstructural analysis as reported in below section.

Sample ID	Chemistry	13/4 SS Std. Req. (~290 HV)	Turbine Blade Nos.- Observed Value (%)	
	Elements	CA-6NM	TS01 Base	TS02 Base
Tashiding Runner Blade Samples	C	0.06 max	0.019	0.022
	Mn	1.0 max	0.52	0.56
	Si	1.0 max	0.37	0.40
	Cr	11.5-14.0	12.90	12.97
	Ni	3.5-4.5	3.55	3.57
	S	0.03	0.002	0.004
	P	0.04	0.028	0.031
	Mo	0.4-1.0	0.486	0.494

b) Hardness Testing:

Runner material is tested for its strength as shown in hardness profile below in fig. 5. In fact, the hardness and toughness is the most important property to the runner behaviour particularly in the silt laden water. The hardness observed in base metal as an average value is 270BHN and in weld metal as 305 BHN. However, the hardness observed in nearby crack locations is 323BHN which is higher as optimum hardness for CA-6NM is ideally recommended between 290-300 BHN which is most optimized with other properties.

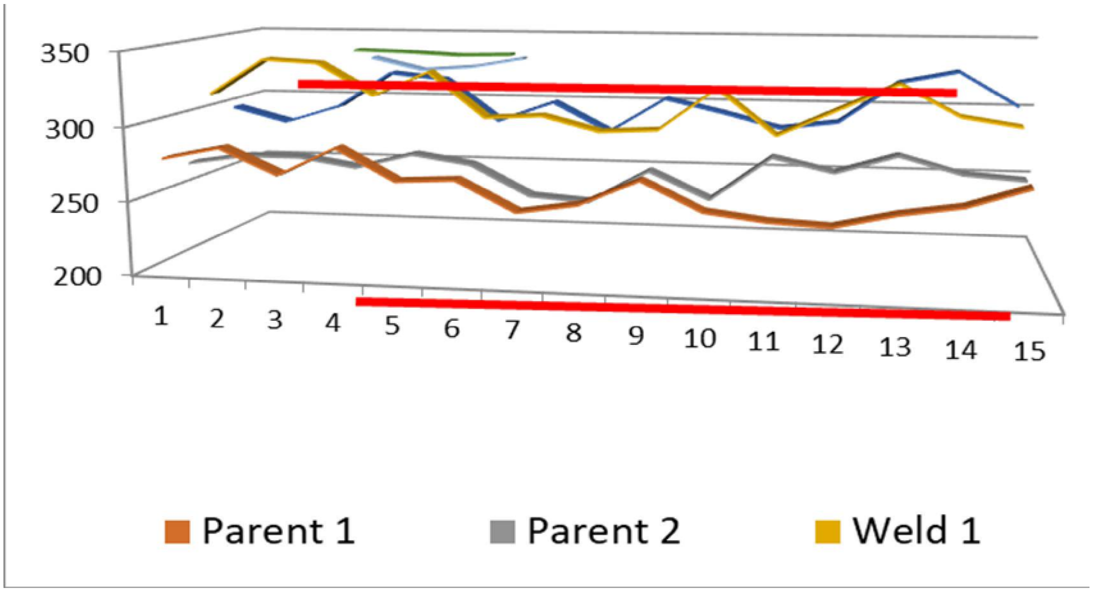

Fig.5: Hardness profile of different regions showing variations in hardness value.

c) Microstructureal Analysis

The metallurgical examination of cracked locations was carried out on cut sample by microstructural analysis at site. The general view of Filed Metallography is shown in fig.6. The microstructure of blades from different locations (Sample TS-01) & (Sample TS-02) taken are shown in figs.7-8. Sample TS-1 consists of base metal and welds metal both and cut from just below the blade where crack was formed. The base metal micro-structure shows bainite and retained austenite in the matrix and delta ferrite phase at many places (fig.7-8), whereas weld microstructure shows widman-statten structure of bainite and retained austenite.

Fig.6: Francis Blades are under metallurgical examination.

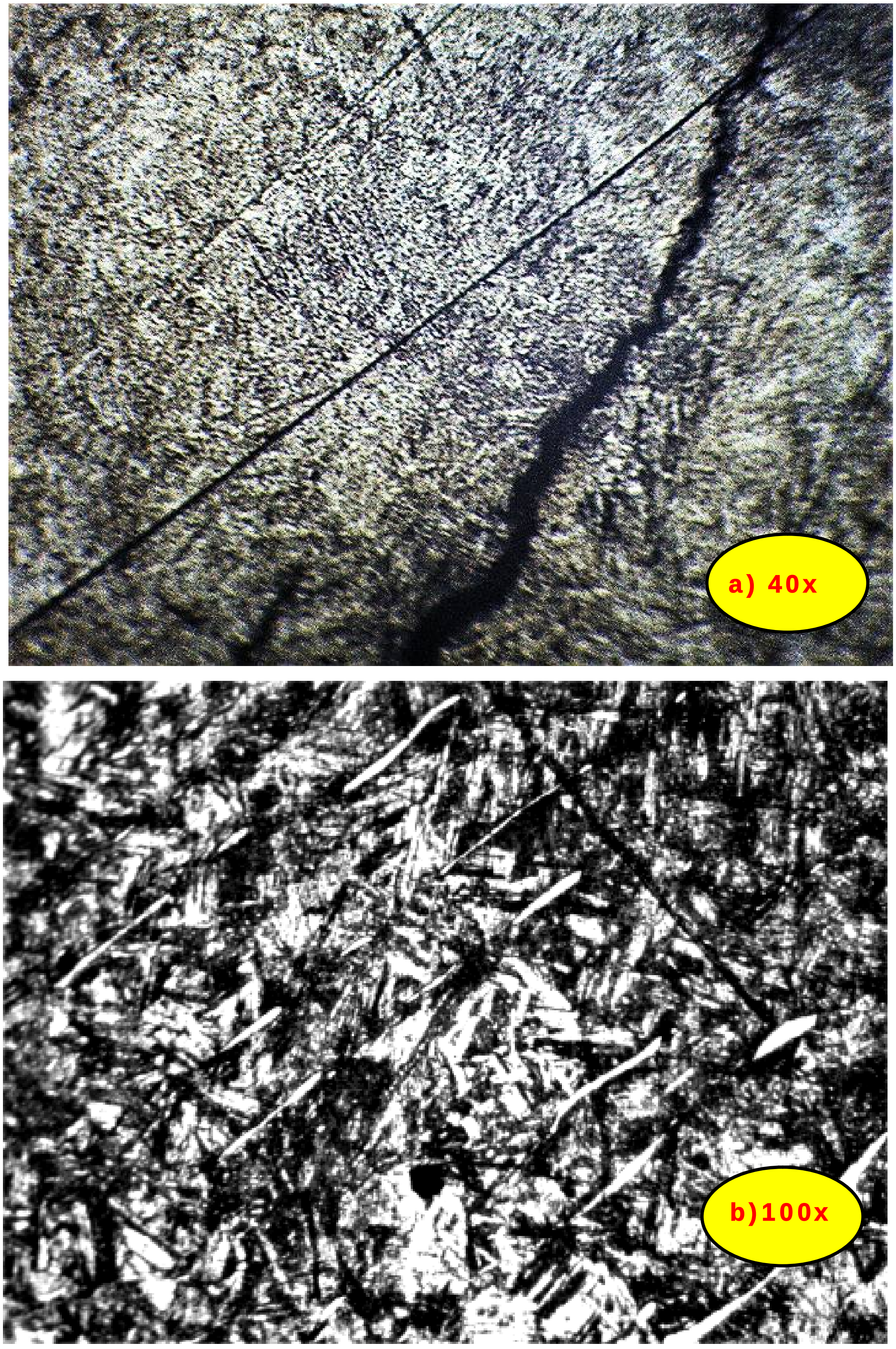

Fig.7: Microstructure of (a&b) base metal of blade at cracked location.

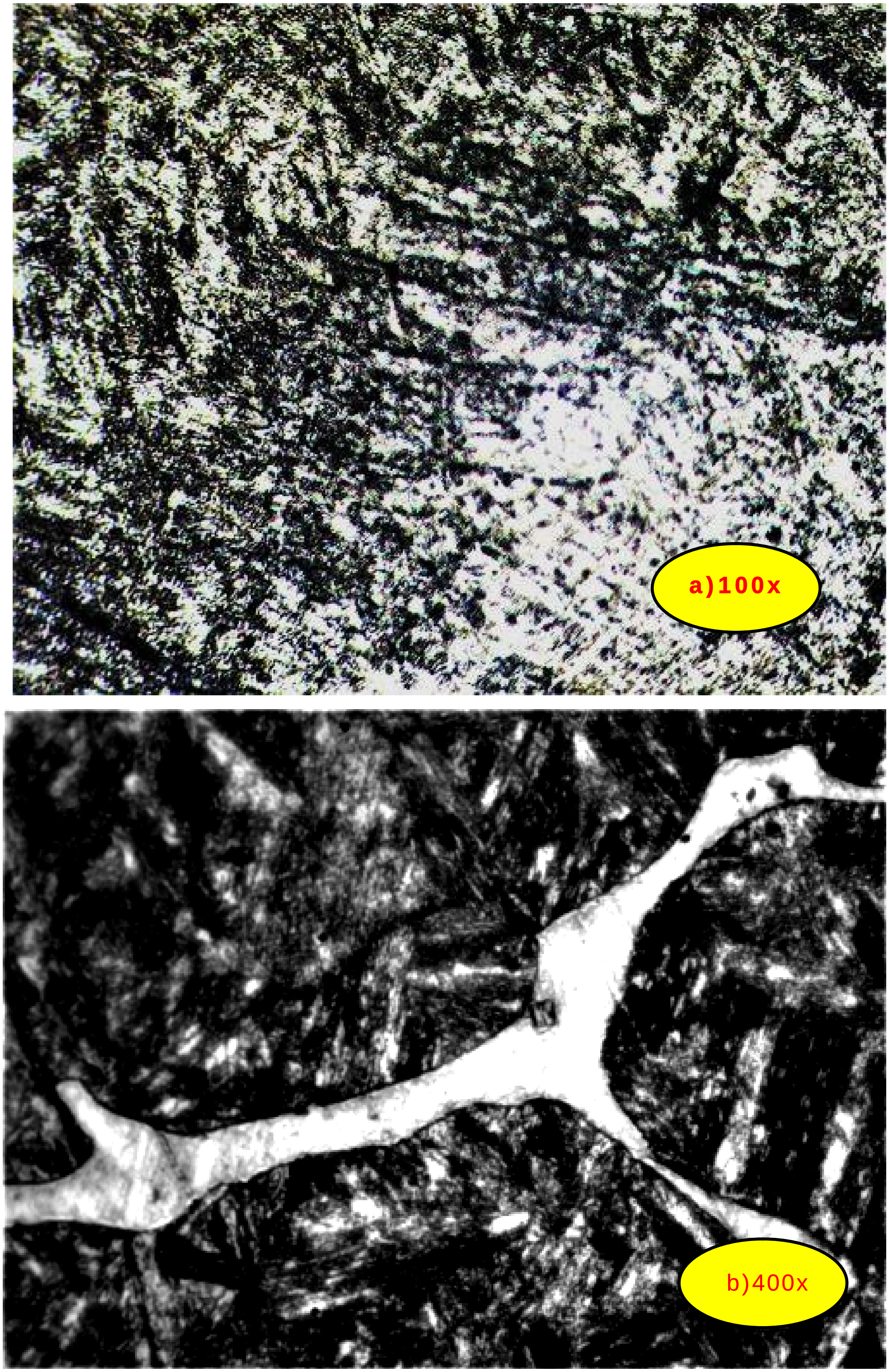

Fig.8: Microstructure of a) weld metal & b) base metal at cracked location.

4.1 CONCLUSIONS:

The following findings observed, and conclusion are drawn from these studies.

1. The runner base materials chemistry is 13/4 Cr-Ni SS and this is acceptable.
2. Hardness seems to be on lower side in base metal but weld hardness is in order. But large variation in hardness in crack affected area and unaffected base metal of bottom ring were noticed.
3. Metallurgical examination shows the weld metal structure is in order, however ring micro-structures have deficiency due to partial transformation of meta-llurgical structure, particularly undesirable phase which is delta ferrite. FMR reveals bainitic and retained austenitic structure, however, where ever cracks are developed in ring, the structure seems to be stressed due to martensitic transformation, hence large hardness variation is observed. Fortunately, no significant casting defects were observed. However, poor heat treatment is done i.e. δ-Ferrite formation which is very prone to significant erosion damage.

CASE STUDY-2: DIKSHI

Dikshi hydroelectric project (24 MW) is located at Phudungto River, west Kameng District of Arunachal Pradesh which is run of River project completed in 2019 and will produce 112.4GWh of power.

a) Visual Examination:

The labyrinth was examined for visual defects or damages. The visual examination shows that there were problems in labyrinths which is cracked at few locations as shown in fig.1 below.

Fig.1. Labyrinth showing cracking on weld joints.

b) Chemical Analysis:

Dikshi labyrinths was tested for its chemistry, hardness & micro-structural analysis as shown in table-2.1 below.

Labyrinth Metallurgy:

Table-2.1: Chemical Analysis of Dikshi Runner blade.

Lab ID	Chemistry	Observed Value in % - Labyrinth Nos.		
		SS 410/217	Sample-01	Sample-02
CH/ 2206/ 03 & 04	C	0.15 max	0.12	0.16
	Mn	1	0.85	0.68
	Si	1	0.52	0.67
	S	0.03	0.015	0.016
	P	0.04	0.025	0.025
	Cr	11.5-13.5	11.67	11.76
	Ni	0.5 max	0.32	0.44
	Mo	-	0.10	0.12
	Al	-	0.030	0.029
	Cu	-	0.067	0.12
	V	-	0.053	0.060
Remarks: Chemical Composition shows the grade is 410 SS/ Not 13/4 SS.				

d) Hardness Testing:

As per standard requirement for the grade CA-6NM (13/4 martensitic stainless steel), the best optimised hardness is ~ 300HV. The hardness observed in labyrinth is shown below in table 2.2.

Table-2.2 Hardness Measurement

Sr. No.	Parent 1	Parent 2	Parent 3	Weld 1	Weld 2	Weld 3
Sample-1	246	237	265	-	-	-
Sample- 2	246	265	286	447	371	423
Average	246	251	275	447	371	423

e) Microstructural Examination

Labyrinth was examined for their metallurgical analysis. Microstructural analysis carried out in labyrinth crack locations of two different labyrinths i.e. lower and upper labyrinths. Micro-structural examination of labyrinth shows tempered martensite and retained austenite structure as shown in Fig.2-3. However, large number of inclusions were observed in the structure as shown in shows tempered martensite and retained austenite structure as shown in Fig. 2b. Microstructure shows the tempered martensite and retained austenite structure and showing oxides inclusions. Labyrinths seems to be repair welded earlier as seen in the micrographs fig.3 This figure showing weld/HAZ and base metal microstructure. Base metal micro-structure showing martensite and austenite whereas weld microstructure showing martensite. HAZ structure is having coarse grain structure (fig.3a) and weld structure showing crack in the area (fig.3a).

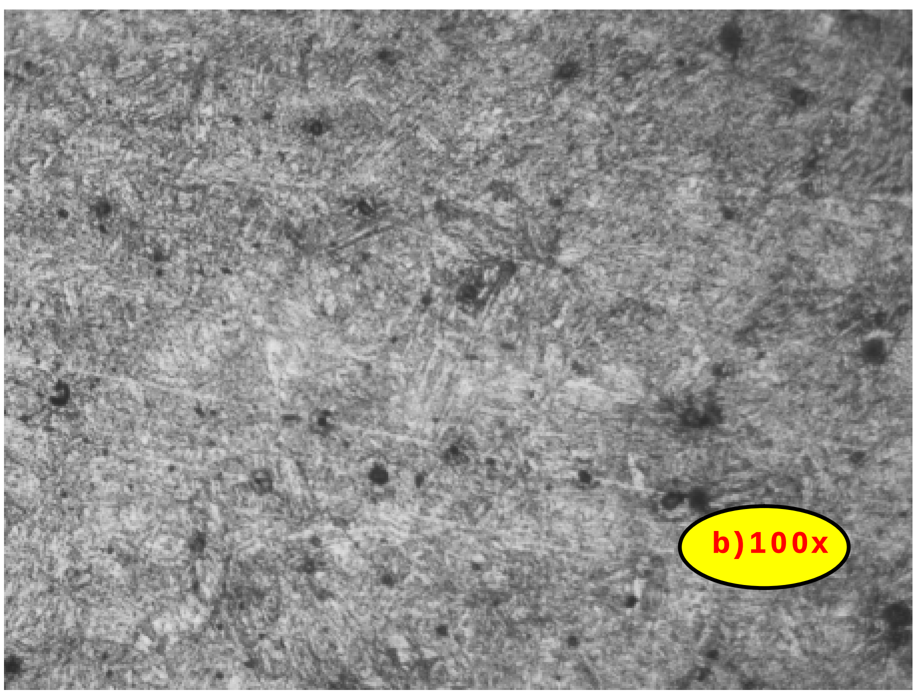

Fig.2: Microstructure a) Base+weld, b) base metal nearby cracked location.

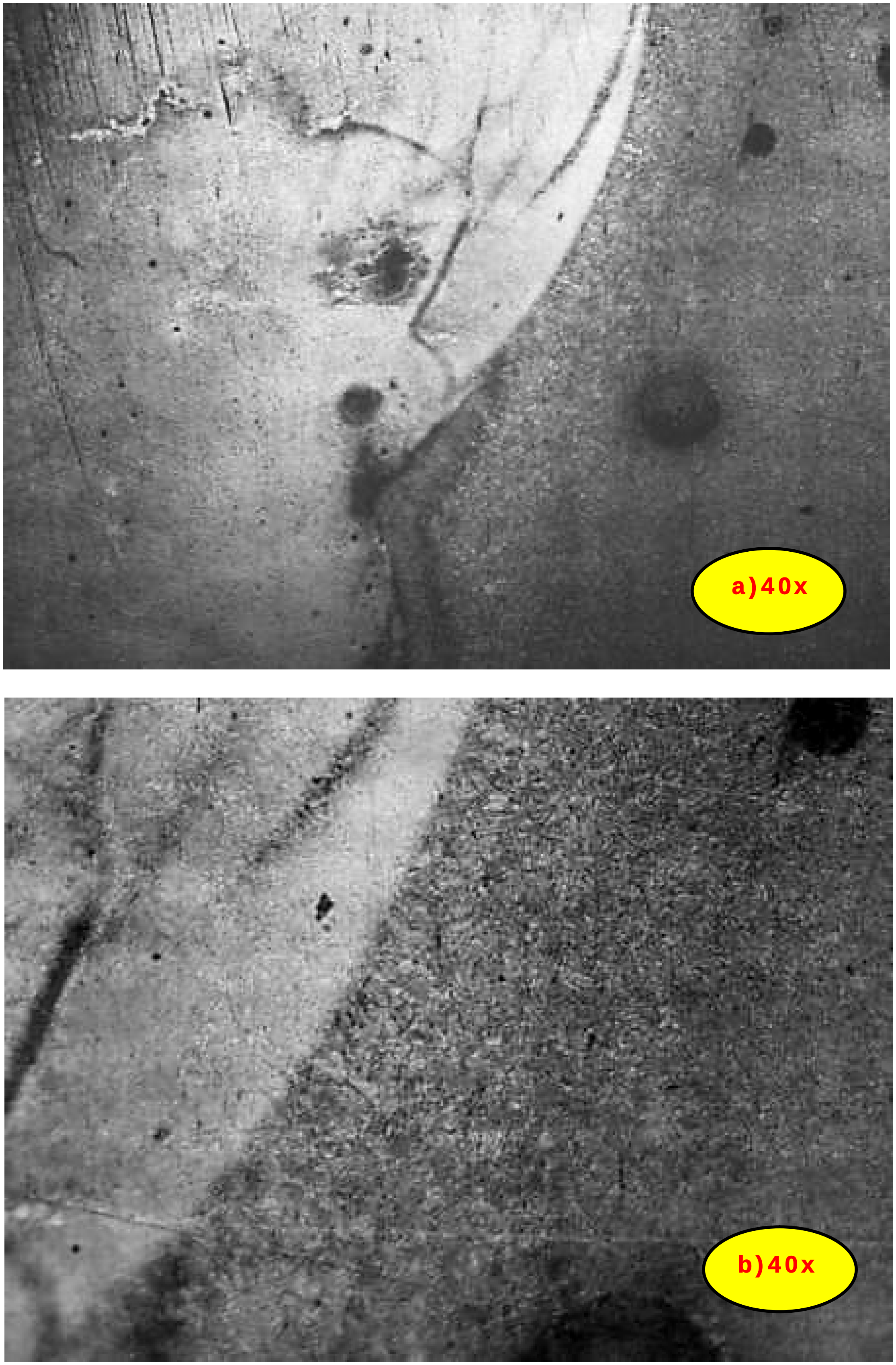

Fig.3: Microstructure a) Weld & HAZ & b) Weld + Base metal.

6.1 CONCLUSIONS:

The labyrinth's study observations and conclusion are as follows.

1. Labyrinth material chemistry found of 410 stainless steel instead of CA-6NM (13/4 SS).
2. Base metal hardness observed 246-275 BHN whereas weld metal hardness observed 371-447 BHN which is quite higher than base material.
3. Labyrinth base metal microstructure is tempered martensite and retained austenite whereas weld metal microstructure is very fine martensite and having multiple cracks.
4. HAZ region containing various coarse zone of structures.
5. Labyrinths failure is due to large variation in hardness and heterogeneity in microstructure.

About Authors:

Dr. MK Sharma obtained his Doctorate Degree in Metallurgy from IIT Roorkee and continue there as a Research Scientist. He joined ERDA 1997 and worked there as Head of NDT & RLA group in Materials Technology Deptt. After then he worked in different MNC such as Head-Technology Center, Alstom Hydro, G.M at Andritz, V.P-Welspun. In 2013, he joined DNVGL, Europe (Norway) as Global V.P where he was Approval Authority for Materials, Welding & Subsea Pipelines for 105 countries. He returns to India in 2018 and since then he is Director of AVIS.

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Prof. Singh has worked with several premier industrial organisations in the country namely BHEL, ABB, L&T Power, L&T-S&L etc. He has also worked as a Professor of Mechanical Engineering with SP University, Vidyanagar, Anand. At present he is active as a Trainer & Consultant. He is a Fellow & Member of several professional bodies and has been on several governmental committees at the national and state level.
"Engineering Excellence and Achievements Award" was conferred to him by the SPE (India), Vadodara Chapter in 2003 & 2007. "International Business Excellence Award" was conferred upon Prof. AK Singh by International Study Circle in recognition of the notable contribution made by him towards stupendous growth of his organization ERDA. "Power Engineering Services Award-2019"was conferred upon Prof. AK Singh by SPE(I), Vadodara.

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He worked as Project Director of Joint Venture between Alstom and RusHydro in Russia from 2012 to 2014. Subsequently, was deputed as Chief Technical Officer to Bhutan Hydro Services Ltd. to set-up and guide the facility at Bhutan. He retired from Alstom as Technical Director in 2015 Worked as Consultant to Lanco in 2016 and to GE from 2016-2018. Presently He is associated with AVIS as a Chief of Design & Engineering Hydro Services.	

Metallurgical Aspects in Bare Overhead Conductors & OPGW for Power Transmission and Distribution

By
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1 INTRODUCTION:

1.1 Overhead lines are the backbone of every electrical power transmission system. Without overhead lines, it is not possible to use power plants with high output because the consumers are not concentrated at the location of the generation. Therefore, transmission line systems like overhead lines or power cable are in use to connect the power plants and the consumer. To increase the reliability many power plants and consumers are connected to an integrated network.

1.2 The Transmission system is to deliver bulk power from power stations to the load centres and large industrial consumers beyond the economical service range of the regular primary distribution lines whereas distribution system is to deliver power from power sector or substations to the various consumers. This transmission and distribution system can employ either overhead system or underground system. Transmission of power, overhead system mainly due to low cost and some other advantages.

Today, most overhead transmission lines use ACSR conductor construction. Steel can withstand high temperatures up to 200°C with no changes in the conductors properties, aluminum on the other hand starts losing its mechanical properties when the temperatures is higher than 90°C. Hence the power transmission capacity of line is limited due to metallurgical aspect of Bare Overhead Conductors. Due to right of way problems, transmitting large quantum of power on transmission lines is inevitable. The generation c is an answer to this as they operate at temperature above 90°C and deliver higher quantities of power.

1.3 The presentation gives brief account of new generation conductors.

2 CONSTRUCTION

2.1 Overhead phase conductors and shield wires are constructed of a stranded group of smaller wires. At transmission voltages it is most common to see stranded conductors. While most stranded conductors consist of a number of round strands, there are special conductors that include layers of trapezoidal strands. Conductors having these trapezoidal strands are commonly called trap wire and distinguished from other conductors with the addition of a '/TW' to the conductor's name. The number and size of strands depends of the type and size of the conductor. Following is a summary of more common conductor types:

2.2 Conventional Conductors:

- ❖ **AAC (All aluminum conductor)**

(AAC) is a low-cost conductor that offers good conductivity and corrosion resistance, but only moderate mechanical strength. Therefore, they are preferred for Distribution Lines laid with smaller spans between supports.

- ❖ **ACSR (Aluminum conductor steel reinforced)**

(ACSR) is the most common

conductor found on existing transmission lines. It consists of a steel core surrounded by one or more layers of aluminum. The steel core may consist of 1, 7, or 19 galvanized steel strands. This steel core may be surrounded by up to three layers of aluminum strands, which may be of the same or different diameter from the steel strands in the core. The high tensile strength coupled with the good conductivity the ACSR conductor is still first choice of utilities.

- ❖ **AAAC (All aluminum alloy conductor)**

(AAAC) is similar in construction to the AAC except that the aluminum strands are replaced with an aluminum alloy that yields greater mechanical strength while maintaining excellent conductivity and corrosion resistance. These conductors are typically used in corrosive environments when the required strength is greater than that provided by an AAC conductor.

- ❖ **ACAR (Aluminum conductor alloy reinforced)**

(ACAR) is similar in construction to the ACSR except that the aluminum strands are replaced with an aluminum alloy that yields greater mechanical strength than ACSR while maintaining excellent conductivity and corrosion resistance. These conductors provide a very good balance between the mechanical and electrical properties therefore makes ACAR the best choice where the ampacity, strength and light weight are the main consideration of the line design.

- ❖ **AACSR (Aluminum alloy conductor steel reinforced)**

(AACSR) is similar in construction to the ACSR except that the galvanized steel core is replaced with an aluminum alloy core that gives the conductor higher mechanical strength that AAC conductor while maintaining corrosion resistance properties in the core. These conductors are used for extra-long spans with heavy load.

- ❖ **ACSR/AW (Aluminum conductor aluminum clad steel reinforced)**

(ACSR/AW) is similar in construction to the ACSR except that the galvanized steel core is replaced with Aluminum Clad Steel wires. Aluminum Clad Steel consists of steel strands with a thick aluminum cladding in place of the typical galvanizing. The mechanical properties of ACSR/AW conductors are similar to ACSR conductors but offers improved ampacity and resistance to corrosion because of the presence of aluminum clad steel wires in the core. These conductors are better replacement for ACSR conductors where corrosive conditions are severe. In addition, they also afford higher ampacity at higher temperature.

2.3 High Conductivity / High-Capacity Conductors

- ❖ **Compact (Trapezoidal ACSR conductor)**

ACSR/TW conductors replace round wire strands of ACSR conductors with trapezoidal shaped aluminium strands. This places a larger volume of aluminum within the same cross-sectional diameter, increasing the power transfer capability without increasing the projected wind area and resulting loads on the conductor and its support structures.

They are designated by adding /TW to the conductor designation (e.g. ACSR/TW).

- ❖ **Higher conductivity AAAC (AL59 or Equivalent)**

(AL59) is similar in construction to the AAAC except that the aluminum alloy strands provide a high conductivity together with the moderate tensile strength. 15% to 30% more ampacity with same sag & less working tension as compared to ACSR. It can be operated at maximum operating temperature of 95°C. These conductors are preferred by RE developers for high power transfer with existing tower designs.

2.4 High Temperature Conductors

❖ **TACSR (Thermal resistant Aluminum alloy Conductor Steel Reinforced)**

TACSR Conductors are very similar in construction to a conventional ACSR conductor but the EC Grade Aluminum wires are replaced with Hard Drawn Aluminum wires of Heat Resistant Aluminum Alloy (generally known as TAL. TACSR can be safely operated continuously above 150°C enabling to pump more current through the conductor. Where there is a need to transmit higher power but restrictions on getting new power corridors approved, various Types of TAL conductors are one of the best creative solution options to utilities. Ability of the Zirconium doped aluminum alloy to maintain its electrical and mechanical properties at elevated temperatures makes these conductors a very cost-effective solution in refurbishing the existing lines with enhanced capacity.

2.5 High Temperature Low Sag Conductors (HTLS)

❖ **ACSS/TW (Aluminum Conductor Steel Supported)**

Aluminum Conductor Steel Supported (ACSS or ACSS/TW) is a composite concentric-lay stranded conductor with one or more layers of annealed 1350-0 aluminum wires of either circular shape or the trapezoidal shaped on a central core of Galvanized Steel core or aluminum clad steel core or Mischmetal coated Steel Core. In an ACSS, under normal operating conditions, the mechanical load is mainly derived from the steel core as aluminum in fully annealed stage does not contribute much towards the mechanical strength. ACSS can be safely operated from 200°C to 250°C (based on the steel core) continuously without losing the mechanical properties. The final sag-tension performance is not affected by the long-term creep of aluminum.

❖ **INVAR Conductor – STACIR**

Super Thermal Alloy Conductor Invar Reinforced (STACIR) conductor has outer layers composed of Super Thermal Aluminium (STAL) alloy wires that can operate up to 210°C. The inner core is composed of aluminium clad INVAR wires. INVAR is a metal alloy with 36% Ni in steel. STACIR/AW conductors are suited for re-conductoring applications. The capacity of existing transmission line can be enhanced by simply replacing the existing conductor without any modification to the tower.

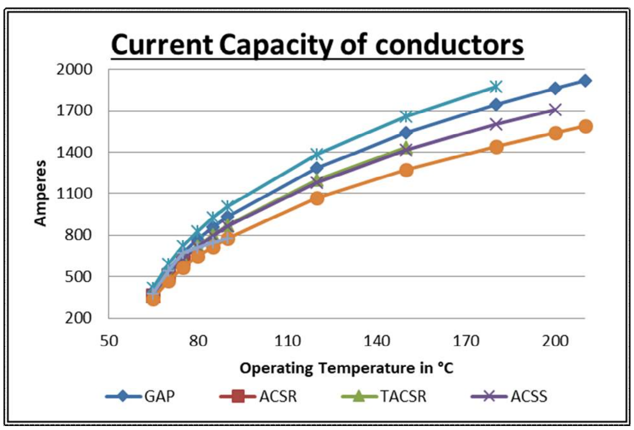
❖ **GAP Conductor – GZTACSR**

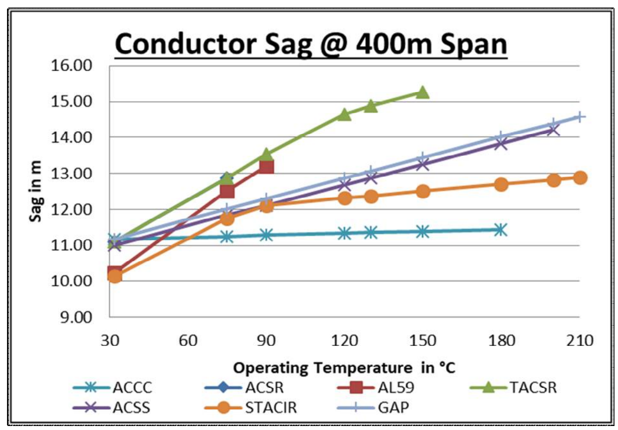
Gap-type Super Thermal resistant aluminum conductor steel reinforced (GZTACSR) uses heat resistant aluminum over a steel core. A small annular Gap is maintained between a high-strength steel core and the first layer of aluminum alloy strands. The gap between the first layer trapezoidal shaped aluminum strands and the steel core is filled with high thermal resistant grease. The principle of the Gap type conductor is that it can be tensioned on the steel core alone during erection. This results in a conductor with a knee-point at the erection temperature. Above the knee point conductor will have a thermal expansion equal to that of steel, while below the knee point temperature it is that of a comparable ACSR. This construction allows for low sag properties above the erection temperature and good strength below the thermal knee point. Presence of heat resistant Zirconium aluminum alloy makes the conductor suitable for continuous operation at elevated temperature (up to 210°C) without affecting its mechanical and electrical properties.

❖ **ACCC (Aluminium Conductor Composite Core)**

Aluminum Conductor Composite core utilizes fully annealed trapezoidal shaped aluminum wires concentrically stranded over hybrid carbon and glass fiber core (Composite Core). The composite core has lighter weight which allows to utilize about 28% more aluminum without a weight or diameter penalty also the core has a much lower coefficient of thermal expansion (CTE) (1.6 ppm/°C) than any other conductor which lets the conductor be operated at a significantly higher temperature up to 180°C without significant sag between poles. This conductor provides lowest sag and highest conductivity hence is best suitable for re-conductoring & New line applications.

2.6 POWER TRANSFER CAPABILITIES OF HPC and HTLS CONDUCTORS





Basis of Conductor Selection:

1. Diameter and Weight equivalent conductors to ACSR Moose for 400kV Rating.
2. Every stress of conductor @ 32°C & no wind condition maintained as ≤ 22% of UTS of ACSR MOOSE Conductor.
3. Values in the graphs are displayed up to maximum designed operating temperatures.

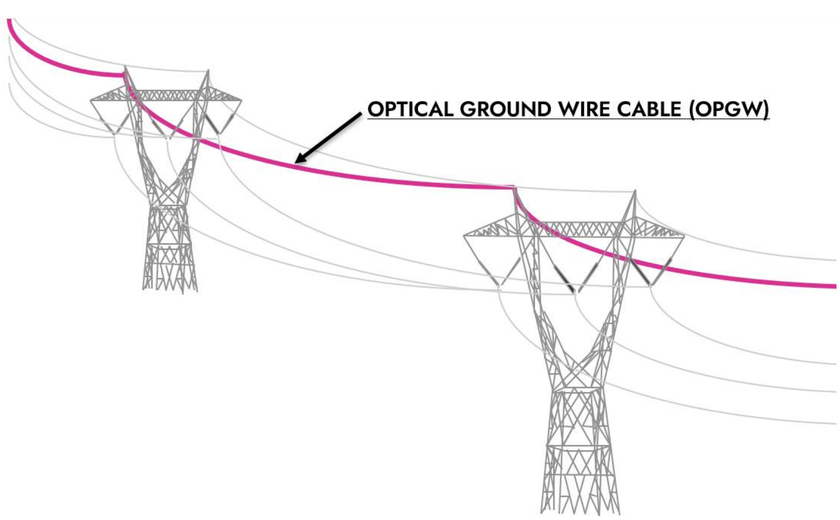
2.7 CONDUCTOR MANUFACTURINIG PROCESS:

3 OPTICAL GROUND WIRE CABLE (OPGW)

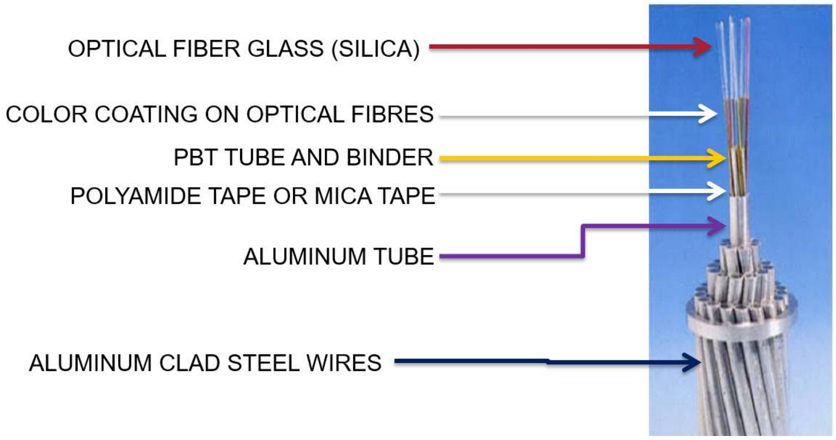
3.1 Optical Ground Wire (OPGW) is a dual functioning cable. It is designed to replace traditional static / shield / earth wires on overhead transmission lines with the added benefit of containing optical fibers which can be used for telecommunications purposes.

The OPGW cable is run between the tops of high-voltage Transmission Towers. The conductive part of the cable serves to bond adjacent towers to Earth ground and shields the High Voltage conductors from Lightning strikes (Atmospheric Discharge).

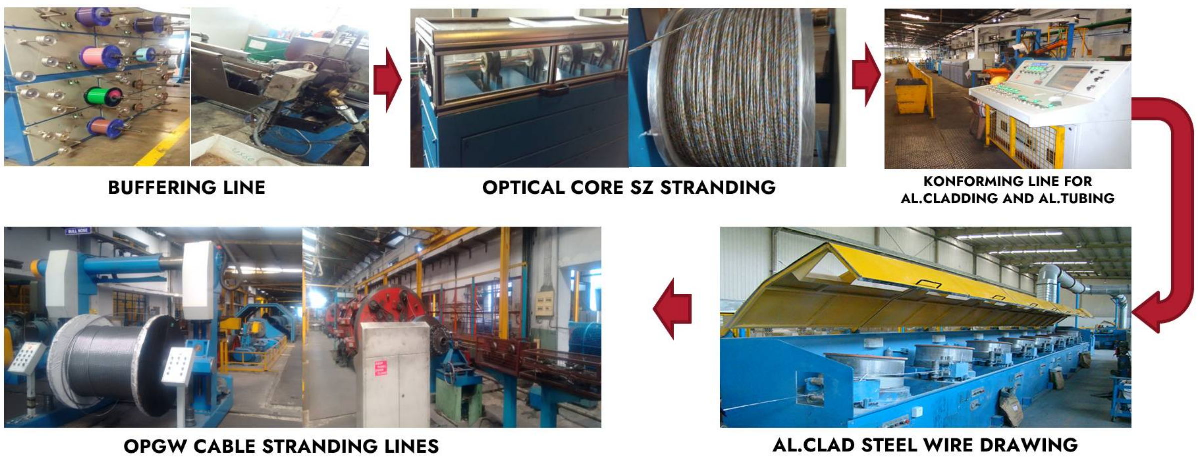
The optical fibers within the cable can be used for high-speed transmission of data, either for the electrical utility's own purposes of protection and control of the transmission line, for the utility's own voice and data communication, or may be leased or sold to third parties to serve as a high-speed fiber interconnection between two points



3.2 SHEMATIC VIEW OF OPGW:



3.3 OPGW MANUFACTURING PROCESS:



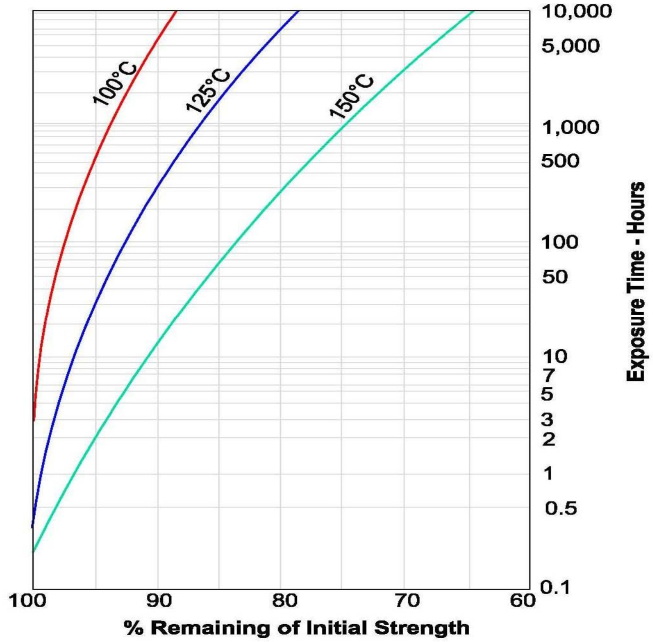
4 THERMO-MECHANICAL BEHAVIOUR OF OVERHEAD LINE CONDUCTOR

4.1 Overhead lines are usually made of aluminum. For improving the mechanical properties high-strength materials like steel or aluminum alloy are in use for reinforcement. In most cases, an aluminum conductor with a steel core is the typical conductor for overhead lines. The area ratio of aluminum and steel is usually between 3:1 to 14:1 depending on the mechanical requirements.

The different mechanical and thermal properties of steel and aluminum lead to a variable force distribution within the conductor. The elongation of an overhead line conductor is the deciding factor of the sag behavior.

The integrity of conductors can be affected by temperature. It is commonly accepted that aluminum begins to anneal at a conductor operating temperature of about 100°C. Annealing results in loss of aluminum strength. For all aluminum conductors, this can be an important consideration.

Annealing is a cumulative effect and is a function of both aluminum temperature and time. Conductors can withstand high fault currents for short times (tenth of seconds) that are many times greater than the load current for which they are designed. A Figure in the Aluminum Electrical Conductors Handbook indicates that an aluminum conductor may lose 5% of its strength after 500 hours at 100°C or 2 hours at 150°C. Aluminum melts at about 650°C.



There are two main effects that add heat and two that remove heat from current carrying conductors. The largest source of heating for conductors is I^2R where I is the line current and R is the resistance per unit length of the conductor. More current causes more heating and higher temperatures cause increased resistance. Both effects must be considered in current rating calculations.

The other effect that contributes to higher conductor temperatures is solar heating. Solar heating is a function of transmission line orientation, time of year, time of day, latitude of the service area, and clarity of the atmosphere.

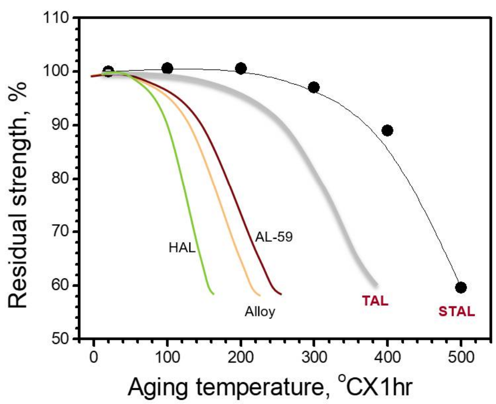
Thus, when the flow of electrons goes through the line, produces heat and the conductor temperature increases. It is necessary to make a thermal study to know if the conductor can stand that temperature. The temperature of the conductor is limited by two factors:

1) The limit of the conductor material

2) Conductor – ground distance or Sag

4.2 ANNEALING CHARACTERISTICS OF ALUMINUM & AL. ALLOYS.

Comparison with other conductors



		HAL	ALLOY 6201	AL-59	TAL	STAL
Density (g/cm^3)		2.7	2.7	2.7	2.7	2.7
Conductivity (%IACS)		61	52.3	59	60	60
Tensile Strength (kgf/mm^2)		16.2 ~17.9	30.2 ~33.1	24.5 ~26.5	16.2 ~17.9	16.2 ~17.9
Allowable Temp. (°C)	*Continuous*	*75*	*95*	*95*	*150*	*210*
	Emergency	85	105	105	180	240
Ampacity		*x 1.0*	*x 1.2*	*x 1.3*	*x 1.7*	*x 2.5*
Applicable Conductor		ACSR	AAAC AACSR	AL-59 AL-57	TACSR TACIR TACSR/AW	GZTACSR STACIR

*HAL : Hard-drawn Aluminum, *TAL : Thermal Resistant Aluminum-Alloy, *STAL : Super Thermal Resistant Aluminum-Alloy

4.3 OPERATING PRINCIPLE OF HTLS CONDUCTORS

Increase the capacity (ampacity) of the line with respect to its equivalent conductor, based on the increment of the working temperature, maintaining the electrical clearances due to low thermal expansion.

Higher working temperature of conductor is achieved with the use of specially treated Aluminum / Aluminum Alloy to preserve their mechanical characteristics or are not subject to a considerable decay even when exposed to high operational temperatures for very long periods of time (in excess of 20 years). Low thermal expansion is achieved by selecting the core material having low co-efficient of linear expansion than steel wires.

At normal operating temperature, the tension on conductor remains distributed on both aluminum and core and as the temperature increases the aluminum strands of a composite conductor starts losing the tension and at a point have no tension or go into compression and all the tension on conductor gets transferred on the core which is caused by difference in values of co-efficient of linear expansion of different material when heated. The point at which all the tension on conductor is taken by the core of conductor is called as knee point (Transition) temperature.

For most transmission lines, maximum final sag is the result of electrical rather than mechanical loads. It is important that any replacement conductor is installed so its final sag under maximum electrical or mechanical load does not exceed the original conductor's final sag and the existing structures need not be raised or new structures added. Under these circumstances, where structure reinforcement or replacement is to be avoided, HTLS conductors with approximately the same diameter and weight can be used to advantage.

HTLS conductors are effective because they are capable of:

1) High-temperature continuous operation above 100°C without loss of tensile strength or permanent sag-increase so that line current can be increased.
2) Low sag at high temperature so that ground and under-build

clearances can still be met without raising or rebuilding structures.

5 ALUMINUM ALLOYS FOR ELECTRICAL APPLICATION

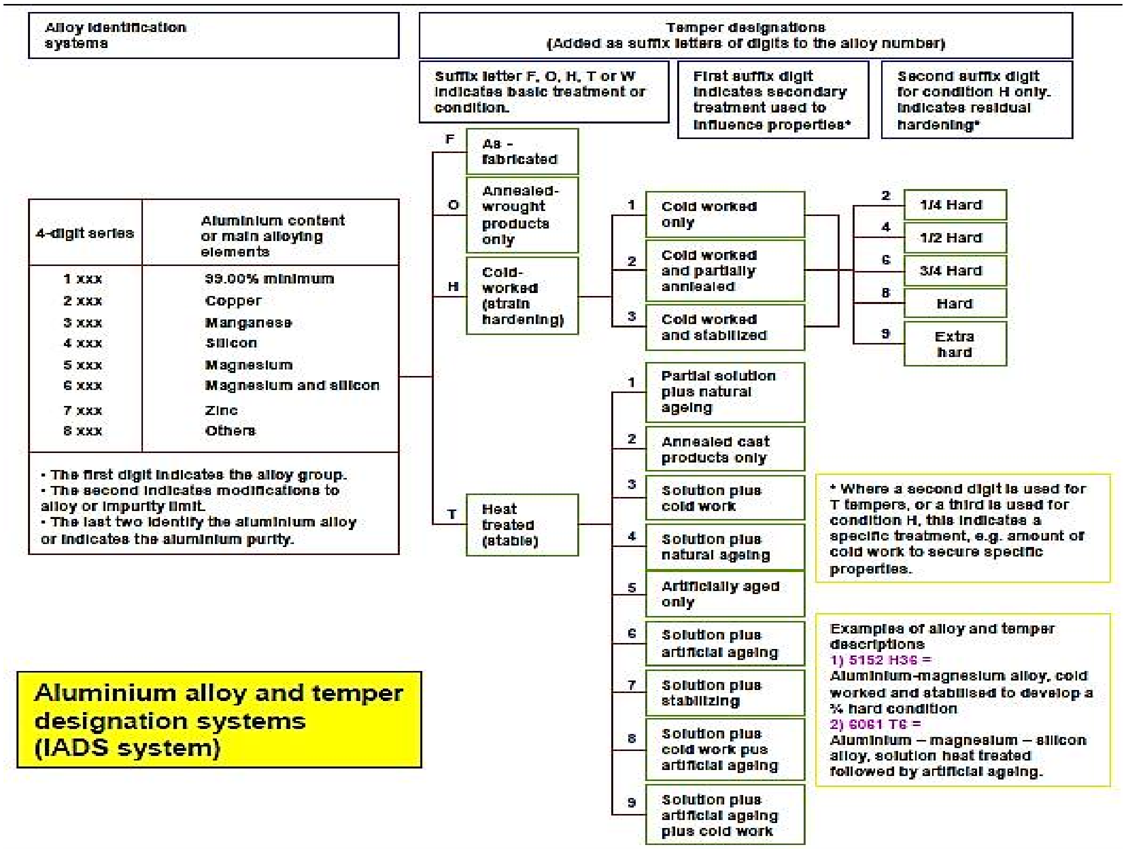
Aluminum Alloy Designation	% Chemical Composition														
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ga	B	Ti	Va	Ti+Va	Other Each	Other Total	AL
1xxx series															
1100	0.95		0.05-0.20	0.05	-	-	0.10	-	-	-	-	-	0.05	0.15	99.00
1120	0.10	0.40	0.05-0.35	0.01	0.20	0.01	0.05	0.03	0.05	-	-	0.02	0.03	0.10	99.20
1350	0.10	0.40	0.05	0.01	-	0.01	0.05	0.03	0.05	-	-	0.02	0.03	0.10	99.50
1370	0.10	0.25	0.02	0.01	0.02	0.01	0.04	0.03	0.02	-	-	0.02	0.03	0.10	99.70
Grade 2 of IS 4026 std.	0.13	0.30	0.04	0.01	-	Cr+Zr 0.01 each	-	-	-	-	-	0.02	0.03	0.10	99.60
6xxx series															
6061	0.40-0.80	0.70	0.15-0.40	0.15	0.80-1.20	0.04-0.35	0.25	-	-	0.15	-	-	0.05	0.15	REM
6063	0.20-0.60	0.35	0.10	0.10	0.45-0.90	0.10	0.10	-	-	-	-	-	0.05	0.15	REM
6101	0.30-0.70	0.50	0.10	0.03	0.35-0.80	0.03	0.10	-	0.06	-	-	-	0.03	0.10	REM
6201	0.50–0.90	0.50	0.10	0.03	0.60-0.90	0.03	0.10	-	0.06	-	-	-	0.03	0.10	REM
65032*	0.40-0.80	0.70	0.15-0.40	0.20-0.80	0.70-1.20	0.15-0.35	0.20			0.20					REM
8xxx series															
8030	0.10	0.30-0.80	0.15-0.30	-	0.05		0.05		0.001-0.04		0.03		0.03	0.10	REM
8176	0.03-0.15	0.40-1.0					0.10	0.03					0.05	0.15	REM
AL59															
AL59	0.20-0.60	0.50	0.10	0.03	0.20-0.60	0.03	0.10	-	0.06	-	-	0.02	0.03	0.10	REM

* Either Mn or Cr shall be present

Thermal Resistant Aluminum Alloy

Aluminum Alloy Designation	% Chemical Composition (Thermal Resistant Aluminum Alloys)												
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ga	B	Zr	Ti+Va	Other Each	Other Total	AL
TAL-AT1	0.10	0.30	0.04	0.01	-	0.05	0.05	-	-	0.10	0.02	0.03	0.10	REM
STAL-AT3	0.10	0.30	0.04	0.01	-	0.05	0.05	-	-	0.40	0.02	0.03	0.10	REM
KTAL-AT2	0.10	0.70	0.04	0.01	0.60	0.05	0.05	-	-	0.40	0.02	0.03	0.10	REM

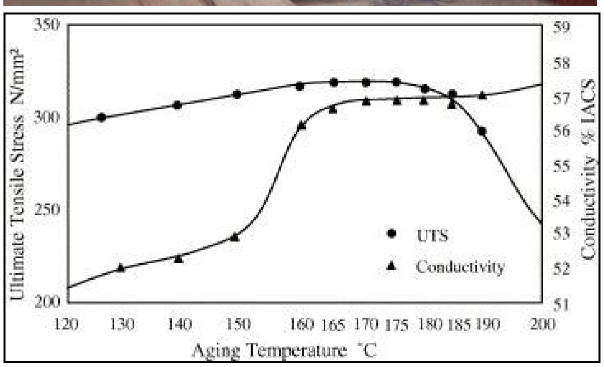
5.1 ALUMINUM ALLOY AND TEMPER DESIGNATION SYSTEM:

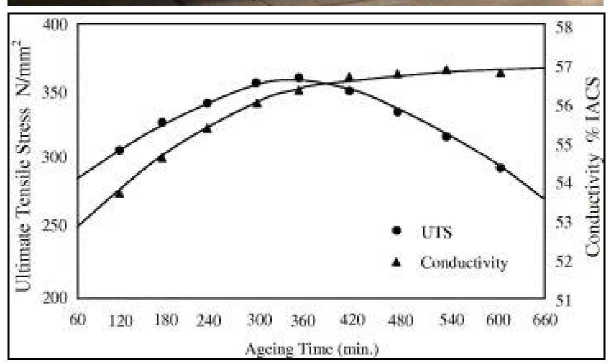


5.2 AGEING AND HEAT TREATMENT

Metal aging is a process used on solution heat-treated metal alloys that can be done artificially or happen naturally. Natural aging occurs throughout the life of the metal alloy. During the natural aging process, super-saturated alloying elements within the metal alloy form what are known as metal precipitates. These precipitates block dislocations in the metal, increasing the strength and hardness of a metal alloy while reducing its ductility.

Artificial aging is a process that is used to accelerate the formation of precipitates in a solution heat-treated metal alloy to a rate that is much faster than the natural aging process. In artificial aging, the metal is held at an elevated temperature for specific duration for it to gain its full strength in a shorter period of time.





6 PROPERTIES OF ALUMINUM & AL. ALLOYS

Materials commonly used in conductors for transmission of electrical currents are aluminum and aluminium alloy. Depending upon the operating temperature of conductor, different Al. Alloys are selected to manufacture conductors.

Designation	A0	A1	A2	A3	A4			AL59	AT1	AT2	AT3	AT4
	AL0	AL1	AL3	AL2		AL4	AL5					
Tensile Strength (N/mm2)	60~95	160~200	295	315~325	250	315~342	295	230~250	155~171	218~248	155~171	155~169
Elongation (%)	20	1.2~2.0	3.5	3.0	3.5	3.0	3.5	2	1.5~2.2	1.5~2.2	1.5~2.2	1.5~2.2
Maximum resistivity at 20 °C (n.Ωm)	27.899	28.264	32.530	32.840	29.984	32.900 Ind 32.600 Ave	32.200 Ind 31.200 Ave	29.30 Ind 29.05 Ave	28.735	31.347	28.735	29.726
Mininum conductivity (% IACS)	61.8	61.0	53.0	52.5	57.5	52.4 Ind 52.9 Ave	53.5 Ind 55.3 Ave	58.8 Ind 59.3 Ave	60.0	55.0	60.0	58.0
Constant-mass temperature coefficient of resistance at 20 °C (10-3/°C)	4.07	4.03	3.60	3.60	3.80	3.60	3.60	3.80	4.00	3.60	4.00	3.80
Density at 20°C (g/cm3)	2.703	2.703	2.703	2.703	2.703	2.703	2.703	2.703	2.703	2.703	2.703	2.703
Modulus of Elasticity (N/mm2)	68000	68000	68000	68000	68000	68000	68000	68000	68000	68000	68000	68000
Coefficient of linear expansion (/°C)	0.000023	0.000023	0.000023	0.000023	0.000023	0.000023	0.000023	0.000023	0.000023	0.000023	0.000023	0.000023
Allowable operating temperature (°C)	250	75	85	85	85	85	85	95	150	150	210	230

7 PROPERTIES OF REINFORCEMENT CORE MATERIAL

The Strength of conductor is determined by the core of conductor.

Core Material with appropriate strength is selected to match the required Breaking load, CLE, Operating temp and weight of conductor which in turn is governed by the tension used at everyday temperature or Factor of Safety.

Wire Type / Properties	HTGS (Regular)	HTGS (EST)	HTGS (UST)	Aluminium Cladded Steel (20SA)	Gulfan EHS & UHS	Al.Invar	Composite Carbon & Glass Fibre Core
Tensile Strength (N/mm^2)	1290 ~ 1450	1500 ~ 1825	1825 ~ 1965	1070 ~ 1340	1450~ 1825	932~ 1080	2137
Elongation (%)	3.0 ~ 4.0	2.0 ~ 3.5	3.0 ~ 3.5	1.5	3.0 ~ 3.5	1.5	1.90
Resistivity at at 20°C. ($\Omega mm^2/Km$)	191.57	191.57	191.57	84.8	191.57	124.94	NA
Conductivity at 20°C. (% IACS)	9	9	9	20.3	9	14	NA
Constant mass temperature coefficient of resistance at 20°C. (/°C)	0.0044	0.0044	0.0044	0.0036	0.004	0.0039	NA
Density at 20°C (g/cm^3)	7.78	7.78	7.78	6.59	7.78	7.1	1.85~1.93
Modulus of Elasticity (N/mm^2)	193000	193000	193000	162000	193000	152000	112300
Coefficient of linear expansion (/°C)	0.0000115	0.0000115	0.0000115	0.000013	0.0000115	0.0000037	0.00000161
Allowable operating temperature (°C)	180	180	180	250	250	250	180

Aluminum-clad Steel Wire

Aluminum-clad steel wire, commonly abbreviated as AW or AS or AC, is an electrical conductor composed of an inner steel core and outer Aluminum cladding. Aluminum clad steel wire is a bimetallic in which aluminum covers on the steel core continuously and evenly.

Class	Type	Nominal Diameter (mm) Over	Nominal Diameter (mm) Upto & Including	Min Tensile Strength (MPa)	Min stress at 1 % elongation (MPa)	Nominal Density at 20℃ (g/ cm^3)	Resistivity at 20℃ (nΩ·m)	Temp coefficient (per ℃)	Coefficient of Linear Exp. (per ℃)	Final Modulus of Elasticity (Gpa)	Radial Thickness of Aluminum Cladding (mm)
14%1ACS	A	1.24	3.00	1590	1410	7.14	123.15	0.0034	12 x 10^{-6}	170	2.3% of nominal wire diameter
		3.00	3.50	1550	1380						
		3.50	4.75	1520	1340						
		4.75	5.50	1400	1200						
	B	2.10	4.00	1770	1550						
20%1ACS	-	1.24	3.25	1340	1200	6.59	84.80	0.0036	13 x 10^{-6}	162	5.0% of nominal wire diameter
		3.25	3.45	1310	1180						
		3.45	3.65	1270	1140						
		3.65	3.95	1250	1100						
		3.95	4.10	1210	1100						
		4.10	4.40	1180	1070						
		4.40	4.60	1140	1030						
		4.60	4.75	1100	1000						
		4.75	5.50	1070	1000						
	B	1.24	5.50	1320	1100						
23%1ACS	-	2.50	5.00	1220	980	6.27	74.96	0.0036	12.9 x 10^{-6}	149	5.5% of nominal wire diameter
27%1ACS	-	2.50	5.00	1080	800	5.91	63.86	0.0036	13.4 x 10^{-6}	140	7.0% of nominal wire diameter
30%1ACS	-	2.50	5.00	880	650	5.61	57.47	0.0038	13.8 x 10^{-6}	132	7.5% of nominal wire diameter
35%1ACS	A	2.50	5.00	810	590	5.15	49.26	0.0039	14.5 x 10^{-6}	122	10.5% of nominal wire diameter
	B	2.50	5.00	880	650						
40%1ACS	A	2.50	5.00	680	500	4.64	43.10	0.0040	15.5 x 10^{-6}	109	12.5% of nominal wire diameter
	B	2.50	5.00	750	550						

7.1 CHEMICAL COMPOSITION OF STEEL WIRES BASED ON THEIR TENSILE STRENGTH

8 TYPE TESTING & VALIDATION OF CONDUCTORS AND OPGW:

Considering the metallurgical aspects of the component or product for design and manufacturing, installation and in-service life where the conductor shall be exposed to thermomechanical cycles, environmental conditions and have force-deterioration.

The tests are classified as under:

Classification		Description
Basic Characteristics Tests		Determine the characteristics of conductors for use in line design
Installation Tests		Relate to conditions that conductors may experience during installation
In-Service Tests	**Mechanical**	Relate to mechanical characteristics imposed on conductors while in-service
	Electrical	Relate to electrical mechanical characteristics imposed on conductors while in-service
	Environmental	Relate to environmental withstand characteristics imposed of conductors while in- service

Tests	HTLS	OPGW
Design & Manufacturing		
Dimensions	√	√
Breaking Strength	√	√
Electrical Resistance	√	√
Stress-strain Curves	√	√
Creep Curves	√	√
Thermal Expansion	√	√
Installation		
Sheave Test	√	√
Radial Crush	√	√
Bend Test	√	√
Axial Impact	√	√
Torsional Ductility	√	-
Twist	-	√
In Service		
Aeolian Vibration	√	√
Galloping	√	√
Corrosion	√	√
Corona & RIV	√	√
Fault Current	√	√
Lightning Arc	-	√
Strain Margin Test	-	√
Temperature Cycle	√	√
Test on Grease	√	√

9 SUMMARY:

The selection of conductor for the transmission line is dependent upon the metallurgical aspects of the component material used in the conductor which is derived from the following factors:

- ✓ The Quantum of power to be transmitted,
- ✓ The amount of current to be handled,
- ✓ Length of the transmission line,
- ✓ The climatic conditions of the terrain, rural, urban, industrial, & oceanic areas
- ✓ Electrical resistance
- ✓ Short time current rating.
- ✓ Lower thermal elongation (per degree C).
- ✓ Higher annealing temperatures.
- ✓ Sag of conductor.

10 CONCLUSION:

10.1 Improved material characteristics and metallurgical properties are required for different options of electrical conductors for overhead transmission lines to overcome the constraints related to Power Sector and improving the power transfer capability of the transmission line.

10.2 The metallurgy and material characteristics that has put forward satisfy every demand and can be used individually or integrated with other Smart and Green Solutions for higher efficiencies.

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Mr. SK Jana is B.Sc., Diploma in Productivity from NPC, PGDMM-IGNOU

He has more than 36 years of rich experience in Design, Manufacturing, Quality Assurance, R&D and new development all family of Cables (Power Cables, Telecom cables, Bare aluminium overhead Power line conductors including HTLS/HPC/OPGW/Rly traction copper cables, Transformer winding cables (CTC & PICC) and associated products. In-depth exposure in design and manufacturing Aluminium and Aluminium alloys, Copper and copper alloys, Steel and steel alloys for various electrical components associated with Power and Energy Sector towards solutions with latest technology for more than 100 utilities globally.

He has worked with: NICCO Corporation Ltd., Odisha, Usha Beltron Ltd., Gulf Cable and Electrical Industries, Kuwait, Usha Martin Ltd., Ranchi and presently working in APAR INDUSTRIES LIMITED (CONDUCTORS DIVISION) as an Asst. Vice President (Operations – Conductor Div.) Head- operations in Conductors, OPGW, Copper business for Rly Tractions, Transformer winding wires and Bus Bar, Head – Technical and R&D Laboratory.

From the year 2000 onwards acted as head of department (QC/QA/ R&D), as management representative of QMS, acted as Pillar head (Quality maintenance) of JIPM.

Certified Auditor/lead auditor from various certification body (BVQI/IQS/SGS/ DQS). Certified from ISI and BVQI on application of SPC/SQC on quality improvement process.

He has excellent exposure in QMS, EMS, OHSAS, ISO 17025, ISO:14067 for effective implementation.

P-Member in BIS TC 37 (Standardization) Co-convener- ETD TC 37/ IEC, Technical convener in IEEMA conductor sub-committee and CIGRE member from 2013, Member in ICDC, Kolkata.

Design, manufacture, type testing of conductors and fittings for lifecycle assessment in Apar R&D laboratory and in association of various Indian and international laboratory (CPRI, ERDA, TAG, DRDO, KERI, SABS, VEIKI, SECRI, CEPRI, SAG, KINECTRICS etc.)

Established advance R&D and type testing laboratory (NABL- ILAC-MRA approved) and also approved by many POWERGRID and many Utilities.

Senior leadership role in Business and environmental sustainability goals.

Has global experience and exposure on Power Utility requirements, Solutions for Utility on power transmission and distribution through design and development of all type of power line conductors and associated accessory including basic guidelines on handling and installation.

HOT DIP GALVANISING (HDG) - PROTECTION PROCESS FOR STEEL COMPONENTS OF POWER SECTOR

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Introduction:

Plain carbon steel is the commonly used material in power sector viz in conductors, girders, poles, tower, other structures, hardware, Transformer tanks etc. Steel is also used in Industries and construction. Steel is mainly iron & carbon alloy. Steel is an excellent material & is readily available, fully recyclable and has a high strength-to-weight ratio, low environmental impact, and long-term durability. However, corrosion of steel is inevitable.

When exposed to the atmosphere, all metals have the natural tendency to revert to the lesser energy state of ore. In simple terms, this natural phenomenon is corrosion, and is most commonly seen as rust in steel. Corrosion causes gradual destruction of the steel through chemical or electro-chemical reactions that take place between the steel, oxygen, and moisture in the environment. Steel objects will corrode faster in coastal regions due to Salty seawater with too much humidity and moisture in the saline air. The corrosion of steel or rust has no structure and occupies approximately six times the volume of the original steel. Rusting causes steel to become flaky weak, degrading its strength, appearance and permeability.

Rusting of iron involves increase in iron oxidation, accompanied by a loss of electrons. Rust consists mainly of two different iron oxides. These vary in the iron atom's oxidation state- Iron (II) oxide or ferrous oxide with +2 oxidation state and Iron (III) oxide or ferric oxide with +3 oxidation state.

The rusting of the steel is a series of chemical reactions which are as follows-

Oxygen is a very good oxidizing agent whereas steel/iron is a reducing agent. Therefore, the iron atom readily gives up electrons when exposed to oxygen.

$$Fe \rightarrow Fe^{2+} + 2e^{-}$$

The oxidation state of iron is further increased by the oxygen atom when water is present.

$$4Fe_2^{+} + O_2 \rightarrow 4Fe^{3+} + 2O^{2-}$$

The iron cations and water molecules now undergo the following acid-base reactions.

$$Fe^{2+} + 2H_2O \rightleftharpoons Fe\,(OH)_2 + 2H^{+}$$
$$Fe^{3+} + 3H_2O \rightleftharpoons Fe\,(OH)_3 + 3H^{+}$$

The direct reaction between the iron cations and the hydroxide ions also produces iron hydroxides.

$$O_2 + H_2O + 4e^{-} \rightarrow 4OH^{-}$$
$$Fe^{2+} + 2OH^{-} \rightarrow Fe\,(OH)_2$$
$$Fe^{3+} + 3OH^{-} \rightarrow Fe\,(OH)_3$$

The iron hydroxides that result as above are now dehydrated, yielding the iron oxides that makeup rust. Many chemical reactions are involved in this process, some of which are given below.

- **$Fe(OH)_2 \rightleftharpoons FeO + H_2O$**
- **$4Fe(OH)_2 + O_2 + xH_2O \rightarrow 2Fe_2O_3 (x+4) H_2O$**
- **$Fe(OH)_3 \rightleftharpoons FeO(OH) + H_2O$**
- **$FeO(OH) \rightleftharpoons Fe_2O_3 + H_2O$**

This result in a reddish-brown deposit called rust, The rusting is not reversible process. Rust is a reddish-brown flaky coat present on the metal. Technically, rust is a Hydrated Iron (III) Oxide whose chemical formula is Fe_2O_3 x H_2O. Simple way of rusting of the iron formula can be represented by the following.

$4Fe + 3O_2 + 6H_2O \rightarrow 4Fe(OH)_3$.

All the chemical reactions listed above have one thing in common: they all require the presence of water and oxygen. As a result, the amount of oxygen and water surrounding the metal can be limited to prevent rusting.

1. Rusting can be prevented by:

1.1. Alloys that are Resistant to Rusting

Some alloys of steel are rust-resistant e.g., stainless steel (which features a layer of chromium -III oxide) and weathering steel. Some special type of steels like COR-TEN steels rusts at a relatively lower rate when compared to normal steel. In this alloy, the rust forms a protective layer on the surface of the alloy, preventing further corrosion. However, these are costly steels.

1.2. Galvanising

Galvanising is the process of applying a protective layer of zinc on a metal. It is a very common method of preventing the rusting of steel.

1.3. Cathodic Protection

1.3.1 Providing the metals with an electric charge can help inhibit the electrochemical reactions that lead to rusting.

1.3.2 This can be done by making the iron/steel a cathode by attaching a sacrificial anode to it.

1.3.3 This sacrificial anode must have an electrode potential that is more negative than that of iron.

1.3.4 Metals that are commonly used as sacrificial anodes are magnesium, zinc, and aluminium. Once they are corroded away, they must be replaced in order to protect the iron/steel.

1.4. Coatings

Many types of coatings can be applied to the surface of the exposed steel in order to prevent corrosion. Common examples of coatings that prevent corrosion include paints, wax tapes, and varnish.

Among all these methods galvanising (Zinc coating) is the simple, long lasting, reliable, cost effective & eco-friendly solution to prevent corrosion of steel components.

2. Hot Dip Galvanising process

Galvanising process includes following steps: -

2.1. Surface preparation

Surface preparation is most important step in any application of coating. Any failure or inadequacy in surface preparation will immediately be apparent when steel is withdrawn from molten zinc bath because unclean area will remain uncoated

2.1.1. Cleaning: Hot (50 -70^0 C) alkali solution (caustic soda NaOH, concentrate controlled 8-10 %) is used to remove organic contamination such as grease & dirt & paint from metallic surface

2.1.2. Rinsing in water: To clean the metallic surface

2.1.3. Pickling: Diluted hydrochloric acid (HCl at room temp with concentrate controlled 8-18%) is used to remove scale & rust from metallic surface

2.1.4. Rinsing in water: To clean the metallic surface

2.1.5. Dipping in flux solution: It is zinc Ammonium chloride (60% Zinc chloride by volume & 40%Ammonium chloride by volume) having pH 4.0.

This is a final step of surface preparation. In this process oxides are removed & also preventing further oxide formation on surface.

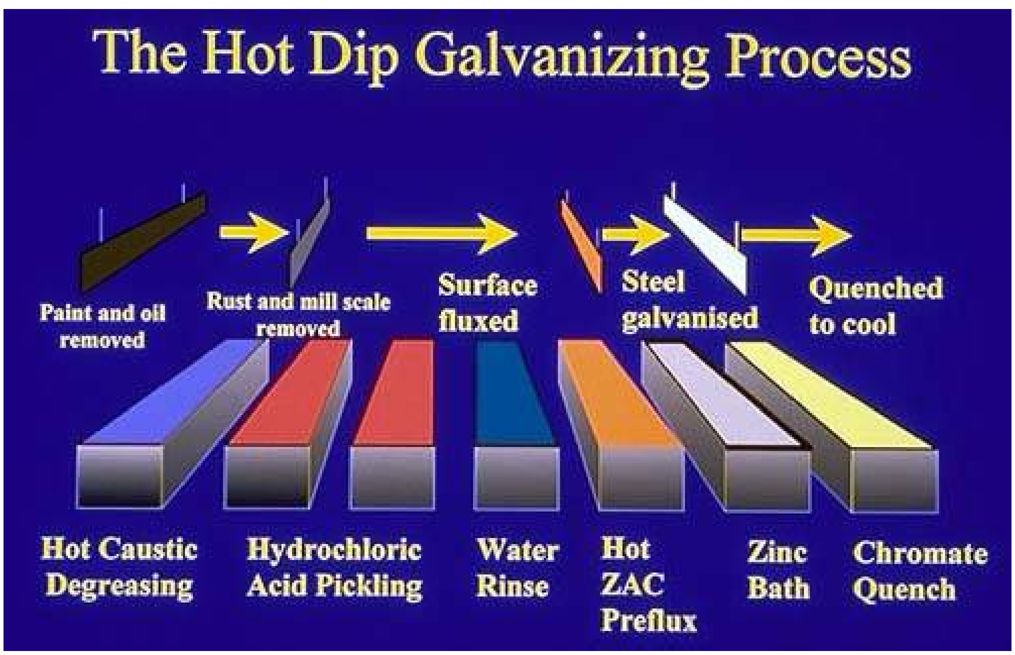
2.2. Dipping in molten Zinc bath:

The fabricated parts are immersed in a molten zinc (Zinc Min. 99% & Aluminium less than 0.007% at temp 440-450^{0}C) until they reach the temperature of bath.

2.3. Passivation: It is a surface treatment on Galvanised parts having Sodium chromate bath ($Na_2Cr_2O_4$) content 300- 1000ppm.

2.4. Drying in normal atmosphere.

2.5. Inspection: - To check the Quality of galvanising for appearance, coating thickness, mass of zinc coating Adhesion of coating & uniformly of coating.



List of Commonly used various BIS specification:

Sr. No	BIS NO	Title
1	2629 1985	Recommended practice for hot dip galvanizing of iron and steel (first revision)
2	2633 1986	Methods of testing uniformity of coating on zinc coated articles (second revision)
3	3203 1982	Methods of testing local thickness of electroplated coatings (first revision)
4	6012 1982	Measurement of coating thickness by eddy current methods (first revision)
5	6745 1972	Method for determination of mass of zinc coating on zinc coated iron and steel articles
6	4759 1996	Hot dip zinc coatings on structural steel and other allied products (third revision) -

3. Properties of the article that affect the results of Hot- dip Galvanising:

3.1. Composition: Unalloyed carbon steel, low alloy steels and grey and malleable cast iron are suitable for hot-dip galvanizing, while sulphur containing free-cutting steels are particularly unsuitable for hot-dip galvanizing. The items of line hardware made by die casting and forging are also galvanized.

3.2. Surface Condition: The surface of the base metal should be clean before dipping into the molten zinc. Pickling is the recommended method of cleaning the surface. Contaminants which cannot be removed by pickling for example oil, grease, paint, welding slags and similar impurities, must be removed prior to pickling. Castings should be as free as possible from surface porosity and shrinkage. The holes should be cleaned by grit blasting (Sand blasting), electrolytic pickling or other methods especially suitable for castings.

3.3. The Influence of Steel Surface Roughness on coating thickness: The surface roughness of the steel surface has an influence on the thickness and the structure of the coating. A rough steel surface as obtained by grit blasting, coarse grinding, etc, prior to pickling gives a thicker coating than a surface which is obtained by pickling alone.

3.4. The influence of reactive elements in the base metal the zinc coating thickness and appearance: Several reactive elements affect galvanizing, for example, silicon (Si) and phosphorus (P) in the steel. The steel surfaces have an influence on the thickness and appearance of the zinc coating. At certain levels, they can give uneven, bright and/or dull dark grey coatings which may be brittle and thick. This is not acceptable.

3.5. Stresses in the Base Metal: Stresses in the base metal are relieved during the hot-dip galvanizing process and this may cause deformation of the coated article. Steel that is cold worked may become brittle, depending on its type and the degree of cold work. As hot-dip galvanizing is a form of heat treatment also, it may accelerate the onset of strain age-embrittlement if the steel is susceptible to such treatment.

Strain age-hardening and the risk of embrittlement is principally caused by the nitrogen content of steel, which in turn is largely dependent on the steel making process. As a general guide, the problem does not occur in modern steel making practices and the basic steels are generally least susceptible to strain age-hardening.

To avoid risk of embrittlement, use a steel which is not susceptible to strain age-hardening. If a susceptible steel has to be used for any reason, avoid severe cold work, if possible. If severe cold work cannot be avoided, stresses should be relieved by heat-treatment before hot-dip galvanizing.

Heat treated or cold worked steels may be tempered by the heat in the hot-dip galvanizing bath and lose some of the increased strength obtained by heat treatment or cold working.

Hardened steel may have tensile stresses of such a magnitude that zinc may penetrate into grain boundaries causing the steel to crack in the hot-dip galvanizing bath. The risk of cracking can be avoided by stress relieving. Usual structural steel is not normally embrittled by the absorption of hydrogen during pickling. With structural steel any absorbed hydrogen is discharged during hot-dip galvanizing. Hardened steels may, however, be embrittled due to hydrogen absorption, if they are harder than approximately 34 HRC, 340 HV or 325 HB. Where experience shows that specific type of steels pre-treatments, thermal and mechanical treatment and hot-dip galvanizing procedures have been satisfactory, the information serves as an indication that an embrittlement problem is not to be expected for the same combination of steel, pre-treatments, thermal and mechanical treatments and galvanizing procedures.

3.6. Larger or Thicker Steel: Longer handling times are needed in the galvanizing bath for larger articles and this as well as the metallurgical properties of thicker steel due to normal manufacturing methods may cause thick coatings to form because the thickness of the coatings is normally a function of the immersion time in the galvanizing bath and the temperature of molten Zinc. For transmission line tower material, the preferred thickness of Zinc coating is 85 micron or 610 gms/M^2.

3.7. Design General: The design of the articles to be hot-dip galvanized should be appropriate for the process of hot-dip galvanizing. The purchaser is recommended to seek the advice of the hot-dip galvanizer before designing or making a product which is subsequently to be hot-dip galvanized, as it may be necessary to adopt the construction of the article for the hot-dip galvanizing process.

3.8. Effect of Process Heat: Any ferrous material which will be adversely affected by the heat of the hot-dip galvanizing bath (typically 440°C but up to 470°C in high temperature hot-dip galvanizing) should not be hot-dip galvanized.

3.9. Enclosed Cavities: It is essential for both safety and process reasons, that means for venting and draining enclosed cavities be provided by the purchaser or after the consent of the purchaser, by the hot-dip galvanizer. As a word of caution, - It is essential to avoid enclosed cavities as these can cause explosions during hot-dip galvanizing.

4. Relation between length of time of corrosion protection and hot dip galvanised coating thickness:

The length of time of corrosion protection of hot-dip galvanized coatings (whether light grey or dull grey) is approximately proportional to the coating thickness and the surface condition of the material to be galvanized. For extremely aggressive conditions (like marine atmosphere) and/or an exceptionally long service life, thicker coatings may be required. The specification of the coating is subject to mutual agreement between the galvanizer and the purchaser. Some increase in coating thickness may be obtained, for example, if steel surface is grit-blasted before galvanizing, or if hot-rolled steels containing more than 0.3% silicon is used.

5. Micro- Structure of Hot Dip Galvanised layer

5.1. During the hot dip galvanising the surface of steel is properly cleaned and then it is immersed in molten zinc. This results in a multiple layered structure of zinc-iron alloy and zinc metal. A metallurgical reaction occurs between the iron in the steel and the molten zinc. This reaction is a diffusion process, so the coating forms perpendicular layer to all surfaces creating a uniform thickness throughout the part.

5.2. A typical hot dip galvanized coating structure consists of four alloy layers as follows:

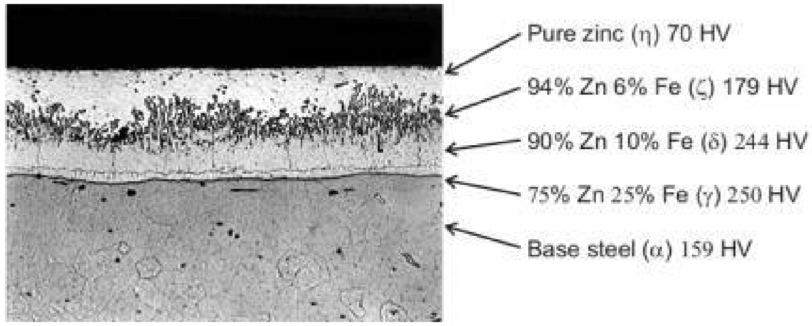
5.2.1. "eta" (100% Zn) at the outer surface which is exposed to open atmosphere. This has hardness as 70HV

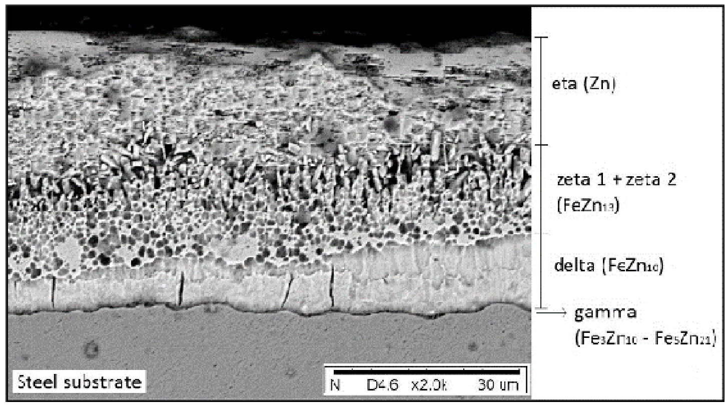
5.2.2. "zeta" (94% Zn, 6% Fe) which is next to outer Zn layer This has hardness as 179HV

5.2.3. "delta" (90% Zn, 10% Fe) which is next to zeta layer; This has hardness as 244HV and

5.2.4. "gamma" (75% Zn, 25% Fe) at the steel/zinc interface. This has hardness as 250 HV

Photographs of microstructure showing different layers of galvanising & hardness





6. Advantages of Hot dip galvanising

Hot dip galvanizing steel offers following advantages and benefits:

6.1. Durable:

One of the inherent benefits of hot dip galvanizing is that when clean steel having thickness greater than 6mm is submerged into molten zinc, it will develop a minimum mean coating of 85 microns (the same thickness as a sheet of A4 paper). This coating thickness will meet the anti-corrosion performance for about 100years.

6.2. Sustainable:

The long-term durability provided by galvanizing is achieved at relatively low environmental burden in terms of energy and other globally relevant impacts.

Several studies have demonstrated the high economic and environmental costs associated with the repeated maintenance painting of steel structures. This burden can be significantly reduced by an initial investment in long-term protection. Lack of attention to optimal corrosion protection can leave a damaging economic legacy of repeated maintenance costs, which may include the cost of loss of power flow due to shut down during painting.

6.3. Cost-effective:

The true cost of protecting steel work from corrosion has to take into consideration two important elements, the initial cost of protection and the lifetime cost.

Hot dip galvanizing is often perceived to be more expensive than what it is actually. There are two reasons for this: Firstly, that such a high-performance coating is automatically assumed to be expensive. Secondly, the initial cost of galvanising compared to paint has changed significantly over recent years. Painting costs have steadily increased while galvanising costs have remained relatively stable.

6.4. Proven Technology:

The galvanising industry is recording increased production year on year. From the smallest components to the largest structural elements, galvanized steel proves itself time and again trustworthy and reliable.

6.5. Reliable:

With proper control over process, Galvanizing is a relatively straight-forward and closely controlled process. The coating formed is consistent and predictable.

There are several reasons why galvanising steel is the most reliable form of corrosion protection? Firstly, as a natural metallurgical reaction is a function of introducing clean steel into molten zinc at a specified temperature – galvanizing is a replicable process.

Unlike a paint coating, the metallurgical bond that is formed through galvanizing becomes part of the steel itself and is not merely a chemical or mechanical bond.

As a natural reaction, galvanizing occurs automatically and does not rely on manual application or require cooling and reapplication of additional layers.

The resultant galvanised coating protects steel from day one and can be depended upon for generations.

6.6. Galvanizing is Honest:

Due to the metallurgical bond that is formed when steel is dipped into molten zinc, a galvanized coating offers straightforward, secure protection from the get-go. Hot dip galvanizing requires rust-free, uncontaminated steel for the process to occur. Once the coating is present, it is impossible for it to fail from underneath. Other coatings can adhere to residual contaminants, this can undermine performance, lead to flaking and cause premature failure.

If you can see a continuous galvanized coating on day one, you can be confident of long-term protection.

Over a matter of months or years, the initial bright, silvery finish will change to form a duller patina as the surface reacts with oxygen, water and carbon dioxide. A complex but tough, stable, protective layer is formed which is tightly adherent to the zinc.

6.7. Galvanizing is Predictable:

A galvanized coating offers predictable corrosion protection that weathers in a linear fashion. Coating thicknesses are measurable and offer lifespans that can be easily forecast and relied upon.

Batch hot dip galvanizing is a standardized process which produces a quantifiable coating thickness.

The coating thickness depends upon the gauge of the steel that is galvanized and is produced consistently across the component, both inside and outside. This can be measured easily throughout its lifetime, using non-destructive methods. Elcometer is an equipment which can be used to measure the thickness of coating.

Articles and its thickness	Local coating (min.) g/M²	µm	Mean coating (min.) g/M²	µm
Steel > 6mm	505	70	610	85
Steel >3mm to ≤ 6mm	395	55	505	70
Steel ≥1, 5mm to ≤ 3mm	325	45	395	55
Steel < 1.5mm	250	35	326	45
Casting ≥6mm	505	70	575	80
Casting < 6mm	430	60	505	70

Galvanized steel coating minimum masses / thickness on articles that are not centrifuged.

Articles and its thickness (Articles with threads)	Local coating (min.) g/M²	µm	Mean coating (min) g/M²	µm
> 6mm dia	285	40	360	50
≤ 6mm dia	145	20	180	25
Other articles (inclusive castings)				
≥3mm	325	45	395	55
<3mm	250	35	325	45

Galvanized steel coating minimum masses/ thickness on articles that are centrifuged

Galvanizing weathers in a predictable, linear fashion. This guarantees that if climactic conditions are stable, the lifespan of a galvanized coating can be correctly forecast, and there will be no unexpected surprises.

The lifespan of the coating is also exceptionally long compared with other forms of corrosion protection and will weather at less than one micron per year in certain climates. The local rate of weathering of any given galvanized coating can be reliably calculated or determined.

6.8. Galvanizing Offers Complete Coverage:

Hot dip galvanizing creates a very strong bond between zinc and steel, forming a coating that will last for generations. Alongside superior strength comes superior coverage, so that galvanized steel structures remain protected, even in the most vulnerable areas.

There are multiple reasons why hot dip galvanizing outperforms other organic coatings. A crucial factor is the way the process achieves complete coverage of a component, both inside and outside.

After an initial cleaning cycle, cleaned iron or steel components are immersed into molten zinc, commonly at around 450°C. The rate of reaction is rapid and a typical time for immersion is only a few minutes. Heavier articles with a high thermal inertia may take longer time.

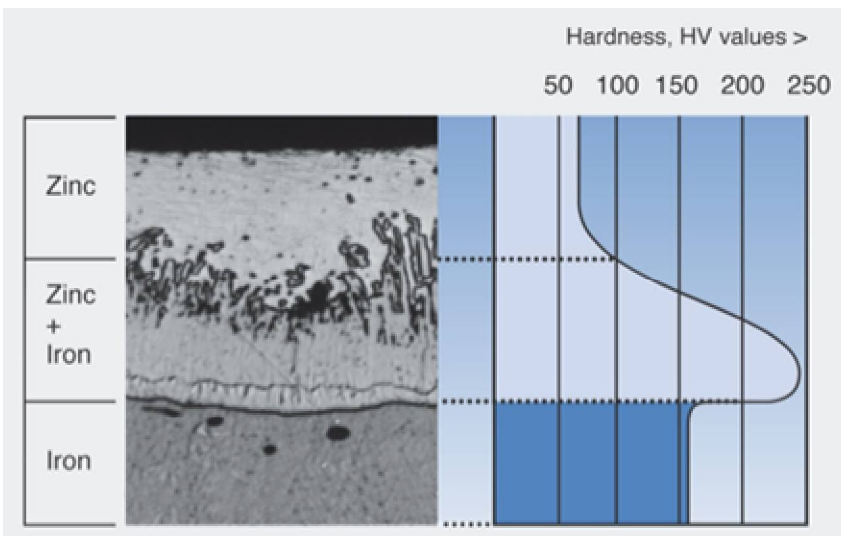
The dipping of steel into a tank of molten zinc via the hot dip galvanizing process means the zinc can access even the trickiest areas.

A further benefit of hot dip galvanizing is that hollow components are coated on internal surfaces too, meaning that a structure will not corrode from the inside. In addition, the coating will also build up at vital corners and edges, unlike brushed or sprayed coatings, which traditionally thin out in these areas.

Hot dip galvanizing is used equally for small components, making sure they are given the same level of corrosion protection as larger articles. Complete structures receive complete corrosion protection.

6.9. Galvanizing is Tough:

Galvanizing has an abrasion resistance up to ten times better than organic paint coatings. The hot dip process is unique, producing a coating which is bonded metallurgically to the steel. As a result, ***galvanized steel*** *has superior resistance to mechanical damage during handling, storage, transport and erection.*



Microsection of a hot dip galvanized steel coating.

A galvanized coating can also help prevent damage during construction, where its toughness can protect components during transport, erection and the other mechanical activities.

Overall a galvanized coating has a high corrosion prevention value. It is extremely hardwearing, long-lived and suited to applications where both mechanical and corrosive protection are paramount.

6.10. Galvanizing Offers Three Way Protection

Hot Dip Galvanizing protects valuable assets in multiple ways and has considerable economic and environmental benefits. It is the most durable corrosion protection on the market and provides optimum performance without the expense or disruption of maintenance procedures. There are three ways a galvanized coating will protect your steel.

6.10.1. Physical Barrier:

A galvanized coating provides a physical barrier which is metallurgically bonded, and prevents the underlying steel from being exposed to atmospheric conditions.

This coating is highly durable and has an adhesive strength of up to seven times that of organic paint coatings. It is a robust, physical barrier comprising a softer, zinc, outer layer which will absorb initial impact loading and underlying layers of strong metallurgically bonded alloys.

These alloys are often harder than the original steel they protect and offer excellent abrasion and chip resistance. As a protective barrier, a galvanized coating weathers at a slow rate and can easily provide corrosion protection for more than 60 years.

6.10.2. Sacrificial Protection:

A galvanized coating will corrode preferentially and slowly. Small scratches on a galvanized surface will not normally require any repair work, and if small areas do become exposed to humidity and other corrosive elements, the galvanized coating will corrode preferentially and at a slower rate than the underlying steel.

This type of protection is called cathodic protection and means the coating will sacrifice itself before it allows the steel to be compromised. It is a key function of the long-term protection offered by hot dip galvanizing.

6.10.3. Prevention of sideways creep:

In the unusual event that a galvanized coating is locally compromised, and bare steel is exposed, the zinc coating will limit damage and prevent a form of corrosion known as sideways creep. Sideways creep can severely undermine paint coatings and is caused as rust deposits accumulate on bare steel and spread underneath and across the paint film. Left untreated, sideways creep will produce peeling and the eventual breakdown of the paint coating. Hot dip galvanizing prevents this kind of deterioration.

6.11. Galvanizing has a Fast Turnaround:

With the right communication you can get steel galvanized within 24 hours.

7. The Environmental Impact of Hot Dip Galvanizing:

The fact is Hot Dip Galvanizing steel does come with several environmental benefits which can help to minimize the overall impact to the environment over the project's life.

7.1. Abundant, Natural Materials:

In hot dip galvanising of steel mainly iron & zinc elements are involved. These are found in abundance in Earth's crust. The base metal is iron ore (steel), which is regarded to be the fourth most found element within the Earth's crust. Hot Dip Galvanizing Coating comprises about 99% of zinc is considered to be a healthy, natural metal. Zinc of over 5.8

million tons is being cycled naturally through the environment. This is done by rainfall, animal, plant life, as well as another natural phenomenon.

7.2. Renewable Resources:

Steel and zinc being both abundantly naturally found are infinitely recyclable. There is found no loss of chemical or physical properties. It effectively means instead of getting down-cycled into the other types of products or its uses, they can be repeatedly used as steel and zinc, without their integrity getting compromised. Hence, when taking into consideration HDG steel's life cycle assessment, this can be termed to be a cradle to cradle product. This is because no 'grave' exists for steel or zinc.

The other wonderful benefit towards minimising the environmental impact is HDG steel's 100% recyclability aspect. Its primary components, steel and zinc can be recycled, which is held crucial. Two recyclability measures do exist which will define ultimately the positive contribution made towards the environment, namely, reclamation rate and recycling rate.

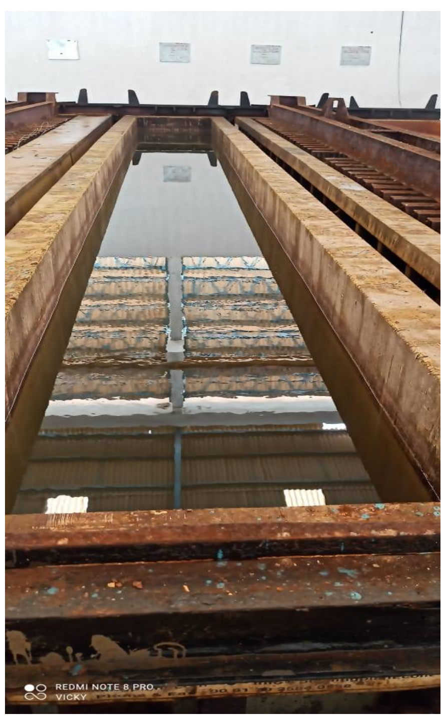
-**Reclamation** rate is said to measure the number of times, the product has been recycled at the end of the useful life.

-**Recycling** content can be termed to be the volume of product which is produced from the different recycled sources.

The world's most recycled material is steel, while zinc boasts of having high reclamation rate. Thus, it leads to having a higher recycling rate, since the reclaimed steel and zinc is put back to use once again. When HDG steel is concerned, structural steel's recycling rate is much better, over 90%. Zinc's recycling rate is much lower since not much zinc is available for reclamation purpose for creating a recycled product. It is its longevity and durability factor that allows it to be used for decades.

8. Summary:

Hot-dip galvanized steel has been used for more than 100 years throughout the world. Galvanizing is specified not only for its superior corrosion protection and durability, but also for its low maintenance, economic benefits, low environmental impact & even aesthetics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METALLURGICAL ASPECTS OF BOILER ENGINEER IN THERMAL POWER STATIONS

BY

Er. VL Dave – Retd. Addl. Chief Engineer
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1.0 INTRODUCTION

Reliable & efficient functioning of power plants is the need of healthy & growing power system of developing country like India. To ensure optimum power output by a thermal unit, requirement is availability of that unit on bar always. Experts have concluded that in a power plant availability of unit is in direct proportion to availability of Boilers that can be achieved by good O&M practices of Boiler wherein Metallurgical Dept. can play a crucial role. That role is explained in detail in this article. It's important & interesting to appreciate the subject in light of various case studies. During my long experience of handling Boilers numerous incidences occurred teaching me important lessons of power engineering. To appreciate brightness, one must be aware of agony of darkness like vice to appreciate importance of Metallurgical Engineering Department in TPS. First I will share my experience of working in boiler department when Metallurgical unit was not part of our set up & that is the first case study:

2.0 CASE STUDY OF MODIFICATION OF TUBULAR APH

Let us begin case study of MODIFICATION OF TUBULAR APH in Skoda make boilers in year 1978 at Shapur PH, which is situated 12kMs away from Junagadh an old power station was with installed capacity of just 16 MW (Two boilers of J&T of 3 MW & two boilers of Skoda make of 5 MW capacity) In older design of small boilers tubular APHs were involved. Over a period of time chocking of APH tubes with ash was common also was common erosion of tubes which we thought of avoiding by removal of tubes & replacement of them with plate type construction. A proposal was forwarded to our HO which in turn asked the data of thinning of tubes. At that point of time and at that place no instrument was available for thickness survey of eroded tubes, so remained hopeless facing problem of boiler draft maintaining. Later I had been to Dhuvaran for my training where I learnt NDT techniques from so called Buch sir from Shapur to generate data of tubes of TPS in support of our proposal. If we had a readily available services of Metallurgist at Shapur, quicker solution of problem could have been found!

3.0 CASE STUDY OF CONSTRUCTION OF STAGE–I BOILER AT WTPS

3.1. In late seventies (say in year 1978) at Wanakbori Thermal Power Station (WTPS) in Kheda district, GEB had commenced a major project of installation of six units of 210MW units of BHEL make. First three units constitute Stage-I and rest of them as Stage-II. In construction activities of Boiler, PRE- INSPECTION plays a vital role for which experienced engineers were required.

3.2. Along with subject knowledge, erectors must have command over NDE techniques which can be broadly classified as conventional techniques and specialized techniques. Conve-ntional techniques are employed judiciously along with construction drawings & erection manuals of supplier. Specialized techniques are to be used for specific problems of critical part's erection for verifying any deviation / damage occurred during transportation / storage which is noticed at site. For this the help of metallurgist is a must. Also important is radiographic evaluation of Weld joints because in power plant erection lot of welding is involved. As site welding is done as per norms it also involves lot of control to be exercised by customer quality output by doing PRE-WELDING TESTING & POST WELDING TESTING especially Radiography testing of weld joints of columns, beams, girders, Pressure part components like tubes, pipes, headers, tanks etc. For useful service life weld defects are to be avoided/controlled to an acceptable limit which is possible with level L1, L2 certified inspectors. Needless to say that the site modifications are common during construction & can be inspected by experts.

4.0 BEFORE & AFTER METALLURGIST ENTERED THE SITE

As boiler construction engineers, we were discharging duties for the scope shown in contract sincerely but honestly without adequate knowledge of weld technology w.r.t construction. After involvement of metallurgical engineers in the year 1982, we had great push in quality assurance of construction activities. Previously all weld joints radiographic evaluation were done by us under influence of BHEL welding engineers but when Respected Vishvkarmaji with his army joined the battle on our side we were better equipped to face challenges of construction activities at WTPS.

5.0 CASE STUDY OF FURNACE EXPLOSIONS

5.1 First it is important to know about EXPLOSION OF BOILER. It occurs after a burner flameout, any fuel like oil, coal can build up inside combustion chamber. It is especially of concern when furnace is hot. The fuels will be rapidly volatize due to temp. Once lower explosive limit is reached, any source of ignition will cause an explosion of vapors. A fuel explosion within the confines of the furnace may damage pressurized boiler tubes & interiors triggering structural failure, steam & water leakage & steam explosions too! Damages are extensive so focus on steps to avoid EXPLOSION but at the same time restoration of furnace is important. The boiler maintenance staff is in tremendous pressure on such mishap as early restoration is the demand from top management. To carry out systematic restoration job one must have firsthand information about damaged components. Metallurgical engineers give great help in identifying damaged components, in fixing the scope of work & methodology to adopt for effective & efficient restoration.

5.2 Checks to be adopted & to be implemented as per requirement are worked out with the help of metallurgical engineers who have lion share in quality assurance. At GTPS in Sep-2005, Unit-2-Boiler explosion occurred on morning of September First. On detail inspection by BHEL experts of explosion on 5/9/05 repair scope worked out & repair done by local agencies including fabrication & erection of expansion joints of all four corners of burner panels.

6.0 CASE STUDY OF BOILER STARVATION AT KUTCH LIGNITE THERMAL POWER STATION (KLTPS)

6.1 Before going to case study let me explain how starvation takes place in running Boiler. When there is no sufficient water level in boiler & fire continues, heat addition will be taking place but no heat transfer so tubes get overheated. Continuation of that situation sends metallic tubes in to plastic deformation state. It's permanent & heavy damage to critical pressure part components. Immediately box up the boiler in order to avoid starvation. Low drum level can occur due to

A) Failure of feed pump
B) Failure of drum level controller
C) Mal operation or negligence of operator
D) Sudden change in load
E) Multiple water tube failure

As loss of water can cause extensive damage to Pressure Part (PP), we may have to maintain level in drum.

Prevent damage to boiler by

1) Trip all the fuel immediately
2) Shut off all the steam outlets from boiler
3) Maintain high air flow initially to aid fast cooling
4) For suspected heavy PP damage, do forced shut down of unit without any further delay
5) When feed water is made available feed at very low rate for restoring drum level. Feed rate to be controlled at low rate to avoid quenching PP components with relatively cold water.

Damage to starved PP components is extensive & mostly beyond repair so replacement is best option but it is time consuming, expensive & forces prolonged S/D of units if timely replaceable components are not supplied by manufacturer which is generally the case.

7.0 REPAIR OF STARVED BOILER AT KUTCH LIGMITE POWER STATION (KLTPS)

7.1 At KLTPS four lignite fired units are working. In Sep-1997, Boiler of unit no. 1 underwent starvation. Supplier & erectors of that unit M/s BHEL initially carried out inspection, damage survey & preliminary budget estimate for entire repair work including supply of new parts. GEB did not agree with time & money estimation of M/s BHEL even at negotiated rate. Therefore, management decided for in house repair. It was my life best experience as I had taken lead role in restoration of that unit amongst many odds

7.2 Initially it was difficult to freeze scope of repair of that boiler because quantum of repair / replacement was not arrived at due to lack of data generation. As services of BHEL was not available we sought help of Er. Vishwakarmaji who camped at KLTPS along with staff of contract agency to take in situ replication of damaged tubes in furnace especially around burner panels which were more vulnerable & most difficult to fabricate & erect at site which was adversely situated having no reliable resources for work of that magnitude at that point of time. Excellent co-operation of Er. Vishwakarmaji made it easy for us to finalize the quantum of work & planning the schedule. Finally BNP was fabricated at site & replaced against all odds.

8.0 BOILER TUBE FAILURE AND HELP OF METALLURGIST

8.1 The worst nightmare of a boiler engineer is occurrence of BTF. It is well known that 60% outages of boilers are attributed to BTF. While leaks can occur for any number of reasons, the main causes of boiler tube leaks are tube corrosion, unified unit corrosion, scale, thermal shock, and improper boiler water treatment (post-installation). Preventing boiler tube leaks and failures starts with understanding why they happen in the first place. There are many reasons for boiler tube failures such as pitting, stress corrosion cracking, stress rupture, creep, erosion, and thermal fatigue. Repair, timely restoration & correct scientific failure analysis are the tasks need Skill, knowledge & experience of experts. Recommendations are derived for prevention of future BTF. Failure analysis of the boiler tubes is main work of a responsible Boiler engineer. In order to examine the causes of failure, various techniques including visual inspection, chemical analysis, optical microscopy, scanning electron microscopy and if needed replication have to be carried out. Tube wall thickness measurements were also performed on the ruptured tube. The plight of Boiler engineer is made easy by experienced, knowledgeable metallurgist using resources at his command including out sourcing. Inspection at location of BTF by Metallurgist is of paramount importance to look at "Failed condition". When arranging site inspection at BTF location metallurgists were just a phone call away. If needed FA can be arranged at resourceful laboratory by Metallurgy Department

9.0 MATERIAL MANAGEMENT & METALLURGY

9.1 For O&M works, Material procurement is important task. According to service conditions & use, material selection proves important for purchase of various components. Suggestion of appropriate material & preparation of its specification is done by Metallurgical Deptt. In case when incomplete / vague / wrong material specifications are provided by Vendors they can be revised on tips of Metallurgists. On receipt of material at store Material identification / cross verification is entrusted to Metallurgical Deptt. Also Preparation of 'Material Map' of boiler tubing system is done which avoids "Material Mix up". Selection of Welding electrodes & Weld processes are done meticulously by Metallurgical Dept.

10.0 Boiler core Group in GSECL

10.1 After formation of GSECL, newer approach in corporate governance was visible to us. The concept of core group materialized in first ever core group, I was member but that set up did not last long so new core group was formed in the year 2007 appointing me as Chairman of that group. The idea was to do brain storming on problems of various boilers at various power stations but in that group no metallurgist was included as member. Functioning of core group needed valuable inputs from metallurgist especially in BTF analysis. Later after great persuasion, Mr. BB Pandya, EE (Met.) was inducted as ex-officio. As a member in boiler core group, his service was very valuable. He was asked to compile the BTF data on monthly basis. His findings along with recommendation were presented in next boiler core group meeting. The routine BTF was not to be discussed in core group but selective BTFs having serious implication needing attention of core group were discu-ssed on submission & moderation by Mr. Pandya. Compiled data sheet sample is in next slide. His input proved valuable in reduction of BTF

11.0 PUFFING OF BOILER

11.1 It is also known as mini or minor explosion of Boiler furnace. A puffing occurs when an oil burner doesn't ignite right away and as a consequence fumes build up in the furnace. The fumes cause an explosion inside the boiler chamber, which vaporizes and expels soot through out of furnace chamber. This problem occurs when unburned oil at the bottom of the furnace is heated. Unburned oil accumulates due to improper ignition timing, leaving a residue of oil that failed to combust after each ignition cycle associate with or without back fire of Boiler. The damage to furnace & PP components needs assistance of Metallurgist for fixing repair scope & early restoration. At WTPS on many such occurrences both departments worked in tandem for quick revival.

12.0 SLAG ACCUMULATION IN FURNACE

12.1 It is very common problem in our boilers where Indian coal of high ash content is used. Coal bottom ash and boiler slag are the coarse, granular, incombustible by-products that are deposited at the bottom of furnaces. When the molten slag comes in contact with the quenching water, it fractures instantly, crystallizes, and forms pellets. The resulting boiler slag is a coarse, hard, black, angular, glassy material. When severe problem at bottom ash hopper discharge occurs , disposal of ash stopped causing excessive accumulation of slag, harden slag is difficult to remove so heap inside build up some time it goes up to firing zone . Such excessive accumulation disturbs boiler draft & made normal BLR operation impossible. Such eventu-ality leads to two major repair zones besides time & energy consuming task of removal of slag from BAH

1) Repair of BAH sealing system involving repair / replacement of Stainless Steels seal plates, seal trough & suspended Stainless Steels wire mesh
2) Repair of goose neck portion above BAH, 'Z' panels of lower Water Wall. Buck stays & supporting system of furnace around firing zone to lower ring header. Here again help from Metallurgist proved very helpful based on Author's experience of Boiler 2 & 4 at Wanakbori Thermal Power Station (WTPS) on different occasions.

13.0 NON DESTRUCTIVE TESTING (NDT)

13.1 NDT services are very useful in Boiler maintenance as testing can be done without destruction of sample. This includes the following.

RADIOGRAPHY – Magnetic Particle Inspection (MPI) (only for ferrous), Die Penetration Test (DPT), US BOROSCOPIC / FIBROSCOPIC EXAM, D – METRE ISOTOPE GAUGING, IN SITU METALLOGRAPHY

13.2 As per ASME Sect. 7 C4, PP failures may be due to the following

A) Over pressure, Over temperature
B) Mal Operation of combination Equipment, Weakening of the PP (corrosion internally & externally)

Failure analysis of each PP is a MUST. Its conclusion helps a lot in preventing future failures. These services are made available by Metallurgy Dept. of Power station. Station wise details of BTF history is maintained centrally at each power station and at corporate office. This data serves as a guideline for doing NDT for various units.

14.0 PLANT LIFE EXTENSION & ROLE OF RESIDUAL LIFE ASSESSMENT

14.1 *An organized programme to investigate, evaluate, and plan for prolonged utilization of existing generation units in order to satisfy future system electric load is termed as PLE*

14.2 By doing PLE we will have safe, reliable, consistent, economical generation of electricity for many more years than plant's predicted life. This is a process of recapturing lost efficiency, improving availability, modifying cycling pattern, enhancement of operational & maintenance techniques. In short, we can list out broadly the following objectives.

- To improve Plant Load Factor (PLF) & Plant Availability Factor (PAF).
- To achieve original or better generating parameters.
- To incorporate latest technologies in system.

14.3 The health of power generating units, area of weakness, why the units are performing below the name plate rating etc. are answered by remaining life assessment of critical components before R&M activities to strengthen the system. The constant condition monitoring helps a lot. Vast data collection, its systematic analysis, correct interprettation & timely corrective measures helps a lot in field of LEP. If the process of deterioration had started then it is utmost necessary to find out the rate of deterioration. This will help in refurbishment at early stage. Seriousness of situation can be judged & accordingly appropriate action may be taken. Here RLA study will play a major role. Based on my experience at Utran GBPS it can be said, for units using gas as fuel this exercise is critically important.

15.0 ABOUT RLA

15.1 It is essential to identify the critical areas where failures are likely to occur and select suitable NDE techniques for detection of such failures. Based on design criticality, past experience and previous failure information, suitable approach in inspection methodologies are adopted. Past experience of successful RLAs done have to be brain stormed amongst experts, user & contractor to decide the METHODOLOGY for RLA. Contingency mechanism has to work out in advance to mitigate surprises & uncertainties.

16.0 ROLE OF NDE TECHNIQUES DURING RLA

16.1 As in complete HEALTH CHECK UP, body tests, Pathological, ECG, MRI – Choosing NDE techniques adopted in the residual life assessment of power plant components plays very important role & can be broadly classified as conventional techniques and specialized techniques. Conventional techniques include Visual examination & Dimensional measurement using appropriate tools, Ultrasonic thickness gauging, testing Magnetic particle inspection using wet fluorescent method and Eddy current test on non-ferromagnetic tubing.

17.0 SPECIALIZED NDE TECHNIQUES

17.1 Specialized NDE techniques which include video probing using fibre optics to assess the damage on the internal surfaces especially for corrosion, erosion, cracks and the presence of foreign materials, in-situ replica technique to study the material degradation and the presence of micro cracks, ultrasonic testing using high frequency pulsar and transducer for measurement of oxide scale on the steam side, ultrasonic attenuation measurement to detect hydrogen damage, bore sonic inspection using multi probes with special attachment to detect cracking in rotor bores and special eddy current technique to detect turbine blade root cracks. Out of various methods, metallographic method has come to stay and is the one favored widely all over the world in view of its several advantages over the other methods. Apart from direct examination of the micro structural condition of the plant component in-situ, the technology of replication of the micro-structure with very high fidelity for examination in laboratory has been developed and widely practiced. The plastic replication technique offers several advantages like high quality equal to or better than that of direct metal examination. Being non-destructive, it is useful for periodic monitoring of plants at specific intervals. The replicas serve as a permanent record of observations and can be stored. Replicas can be examined at high magnifications in SEM with a very high degree of resolution. After employing such techniques important work is to calculate Residual life of important components & eventually life of Boiler

18.0 CALCULATION OF RESIDUAL LIFE

18.1 Data collected from the site are compiled as per Indian Boiler Regulation Act-391, part A (I) & (II) and compare with the available plant history data. Based on the tables prepared and the results available, it is compiled and compared with the above Neuberger and Wedel classification, metallurgical analysis and oxide scale measurement, The expected life of the plant components are thereby predicted, specific points/findings, which needs an immediate attention from the plant authorities is to be get noticed when required. Pressure calculations are also to be carried out on all the components of the boiler.

CONCLUSION

From above discussion based on my practical experience it is clear that Metallurgists play pivotal role in helping core boiler engineers in their ultimate task of running boilers smoothly for years & years economically. I do not have any experience of other organizations where Metallurgical units are stationed at site but noticed that at NTPC for site problems core engineers have to depend on help from head quarter & for minor things at local site Boiler engineers were depending on PLANNING GROUP & CONDITION ASSESSMENT GROUP which have resourceful agencies taking help of metallurgists.

About the Author

Retired as Additional Chief Engineer after serving 36 years in GSECL (Gujarat State Electricity Corporation Limited, erstwhile GEB) at various level & at various power plants. At UKAI Constructed 500MW unit as a project Head & at junior level served in Boiler construction of 6 x 210 MW units at Wanakbori TPS.

ROLE OF CONDUCTOR METALLURGY IN EHV TRANSMISSION LINE DESIGN

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1. INTRODUCTION

1.1. Conductor is the most important and cost intensive component of EXTRA HIGH VOLTAGE (EHV) Transmission lines. Design of other components of line also much depend on the conductor metallurgy and physical properties.

1.2. In yesteryears the most popular conductors for transmission lines were Aluminium Conductor Steel Reinforced (ACSR) & All Aluminium Alloy Conductor (AAAC). They were used to transfer certain fixed amount of power based on the ambient temperature and depending upon their metallurgical and mechanical parameters. With the change in time the emphasis is on transfer of large quantum of power per unit cost of Right of Way (ROW). Thus, the new generation conductors are designed with lot many new metallurgical features.

1.3. The important metallurgical parameters of the conductor which affect the design, are as follows

- Conductivity and resistance (R)
- Co-efficient of Linear expansion (α)
- Modules of elasticity (E)
- Density of conductor (δ)
- Ductility & Creep

1.4. The important mechanical parameters which affect the design are as follows

- Weight per meter
- Overall diameter
- Cross–sectional area
- Normal span for design

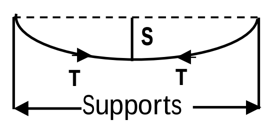
1.5. The important parameters which affect the electrical design of the conductor are as follows

- Skin effect
- Corona
- Inductance (only in A.C. power flow)
- Capacitance (only in A.C. power flow)

2. SAG & TENSION CALCULATIONS

2.1. In order to design the transmission line supports (Towers, Poles etc.) Sag & Tension calculations have to be done as the height of the support is decided by the Sag and strength of support is decided by the tension.

2.2. The basic equation for calculating Sag is as under



Where S = Sag in meters

$S=\frac{WL^2}{8T}$ L = span in meters

T=Tension in Kg

2.3. In the above equation the variable factor is Tension (**T**). It is worth noting that the value of **T** will increase with the increase in wind pressure and value of (T) will decrease with the increase in temperature (**t**). The value of **t** is the sum of the ambient temperature t_1 and the net temperature gained by the conductor due to the passage of current t_2. Thus $t = t_1 + t_2$. Again, t_2 is the product of I^2R where **I** is the current flowing through the conductor and **R** is the resistance of the conductor. The value of **R** for the passage of Direct Current (D.C.) is slightly less than that for the passage of Alternating current. (A.C.) due to the effect of frequency.

2.4. The current carrying capacity of conductor depends mainly on heat balance equation as follows

$P_j + P_{sol} = P_{rad} + P_{conv}$

Where P_j – heat generated by Joule Effect

Where P_{sol} – heat generated due to solar

Where P_{rad} – Radiation heat loss of conductor

Where P_{con} – Convection heat loss of conductor

The above equation clearly indicates that the heat generated due to passage of current through the conductor plus the heat gained from atmosphere has to be balanced by the sum of heat radiated in atmosphere and the heat convection by the metal of the conductor.

2.5. The above equation clearly indicates that the conductor can handle more amount of current if the allowable temperature is raised. The conventional ACSR conductor can be loaded till the conductor surface temperature reaches to 90^0C. After this temperature annealing of Aluminium will start and therefore the entire tension will be taken by steel core. This is termed as the "knee point temperature". This is not desirable for the mechanical performance of the conductor.

2.6. Typical calculations for Ampacity of ACSR "moose" and ACSR "zebra" conductors, based on the heat balance equation indicated above, are given here under:

$P_j + P_{sol} = P_{rad} + P_{con}$

Thus $P_j = P_{rad} + P_{con} - P_{sol}$

Now $P_j = I^2R$ where I is the current and R is the AC resistance of conductor

Therefore, $I^2R = P_{rad} + P_{con} - P_{sol}$

Thus $I = \sqrt{\dfrac{P_{rad} + P_{con} - P_{sol}}{R}}$

The calculations are done with an assumed Ambient as 40^0C and surface temperature of electrically loaded conductors as 75^0C.

The value of AC resistance R at 75^0C for the conductors are as under

ACSR "moose" 0.07011 x 10^{-3} Ohm/M.

ACSR "zebra" 0.0867298 x 10^{-3} Ohm/M.

P_{rad} = Radial heat loss in watts per meter of conductor at 40^0C

The values of P_{rad} for the conductors are under:

ACSR "moose" 6.4073736 Watts/M.

ACSR "zebra" 5.7720816 Watts/M.

Above value are obtained by the product of 2.0168xD where D is the diameter of conductor.

P_{con} = Convection heat loss of conductor in Watts per linear meter of conductor length at 40^0C

The values of P_{con} for conductors are as under:

ACSR "moose" 24.796623 Watts/M.

ACSR "zebra" 23.51297 Watts/M.

The above values are obtained by the equation+ as follows

0.47588 + 13.333 $D^{0.52}$ Where D is the diameter of conductor in cm.

P_{sol} = Heat gained from Sun in Watts/M length of the conductor

The values for the conductor are as follows:

ACSR "moose" 1.14372 Watts/M.

ACSR "zebra" 1.03032 Watts/M.

These values are derived by the product of 3xD where D is the diameter of the conductor.

Substituting the values of P_{rad}, P_{con} and P_{sol} in the equation we can obtain the Ampacity I as follow

ACSR "moose" conductor

$$I = \sqrt{\frac{6.407373 + 24.796623 - 1.14373}{0.07011 \text{ x } 10^{-3}}}$$

= 654 Amp

ACSR "zebra" conductor

$$I = \sqrt{\frac{5.7720816 + 23.511297 - 1.03032}{0.0867290 \text{ x } 10^{-3}}}$$

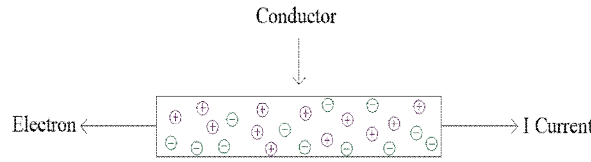
= 570 Amp

2.7. The ampacity will depend upon the metallurgy, ambient temperature and emissivity. Thus, every type of conductor will have different Ampacity.

3. EFFECT OF METALLURGICAL PARAMETERS

3.1. The metallurgical parameters influence the performance of conductor in different manner. They are discussed here under

3.1.1 Conductivity and resistance are opposite to each other. Conductivity depends upon the free electrons available in the molecular structure of the metal. Conductivity also depends upon the speed of the travel of electrons in the metal. Copper has a better conductivity and less resistance compared to Aluminium.



However, due to high cost and problems of theft, Aluminium conductors are being used in overhead transmission for last more than 50 years. Contrary to this the motors and transformer winding are made up of copper coils only. This is for the fact that Aluminium has higher resistance and may damage the insulation due to heating. There are transformers (Distribution transformers) which have Aluminium winding. Majority of control cables are of copper. Power cables can be Aluminium or Copper depending upon the end use and method to dissipate the heat.

3.1.2 The co-efficient of linear expansion (α) for the conductor is another important factor. It is defined as the increase in length per unit original length per degree rise in temperature. This is a type of temperature stress. In transmission line, the conductor is clamped on each tower and therefore, the increase in surface temperature results into increase in the catenary length and the sag. Similarly decrease in surface temperature results in decrease in the catenary length and the sag. Thus, the value of (α) is responsible for variations in sag with the variation in temperature. α is obtained from the type test of the conductor.

3.1.3 In case of ACSR conductor, the values of resistance (R) & coefficient of linear expansion (ɑ) are for the composite cross section covering Steel & Aluminium strands. However, in reality the value of R and ɑ are different for Steel and the Aluminium strands. Depending upon the size of each strand and total number of strands of Steel core and the Aluminium layers, different types of ACSR conductors will have different value of R & ɑ and the knee point temperatures. However, as a thumb rule, the ACSR conductor should be electrically loaded only up to a temperature of 90^0C (which includes ambient of 45^0C). This is covered above.

3.1.4 The conductors made out of Aluminium alloy as well as with annealing can be operated at higher temperature (beyond 90^0) without any change in metallurgical performance. Change in core material or special coating to the Steel material, can allow passage of more current due to high temperature operations.

3.1.5 The modules of Elasticity (E) is one of the most important parameters which determines the conductor behaviour under varied climatic conditions imposed upon the conductor during its life span.

$$E = \frac{\text{Stress}}{\text{Strain}}$$

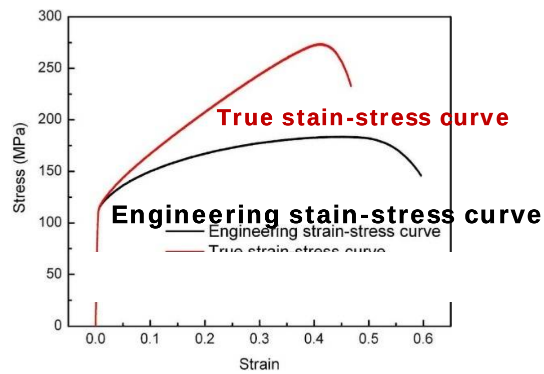
again

$$\text{Stress} = \frac{\text{Load (Tension)}}{\text{Area of Cross Section}}$$

$$\text{and Strain} = \frac{\delta L}{L}$$

Where δL is the increment in length of conductor under tension &

L= length of conductor put to the test. Stress–strain curves of each type of conductor is a reflection of conductor behaviour within the yield limits.

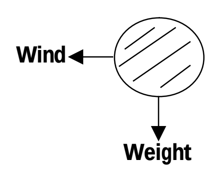


Typical stress-strain curve

3.1.6 The density of conductor is important for calculation of Sag & Tension at varying temperatures and wind pressures.

$$\text{Density} = \frac{\text{Unit weight of conductor}}{\text{Cross–sectional area of conductor}}$$

This parameter helps in working out resultant force on the conductor and ultimately the Tension and Sag at various wind velocity & pressure while in service



3.1.7 Ductility and creep are other parameters. The value of stress, strain & E depends upon ductility and creep (which is a permanent elongation). The initial creep of the conductor is due to assumption of initial Sag & Tension when the conductor is unwound from drums and is laid on the towers. The creep which occurs over a period of time is due to cyclic thermal stresses imposed on the conductor.

A typical set of calculations for creep over a period of time is given here under

The Creep Calculation For AAAC Conductor is Done Using Following Equation.

$e = 0.01165\ (t)^{0.2} \times (1.434 - W_a)\ (P_a)^{1.115}\ (106.58\ Q_a)$

Where, e = Creep in mm/kM

W_a = (Unit weight of steel core) / (Unit weight of conductor)

t = Time in hour for 20 years

= 24 x 365 x 20 = 1,75,200 Hrs.

P_a = Everyday tension in percentage of UTS

Q_a = Everyday temperature 32^0C

Data for Creep Calculations		
	Units	**Values**
Weight of steel core	Kg/kM	0
Weight of conductor	Kg/kM	1255.41
3 Day time	Hours	72
365 Day time	Hours	720
20 Year time	Hours	8760
Watt	Hours	175200

Creep (e) = $0.01165\ (175200)^{0.2} \times (1.434 - 0)\ (25)^{1.115}\ (106.58 + 32)$

= **1049.333 mm/kM**

Final Tabulation of Creep Over Period of Time					
Q_c Temp. (C)	**P_a (%)**	**Creep of AAAC Conductor (mm/km)**			
		for 3 days	**for 30 days**	**for 365 days**	**for 20 Years**
32	25	178.564	349.682	547.264	1049.333

Above table indicates that the creep in conductor is a very slow process.

3.1.8 The ductility test is required to be done only on the current carrying strands of ACSR conductor. As per IS–398 the relative ductility can be established by Torsion test or elongation test. The wrapping test is performed to find the strength of Aluminium & steel cores against the fatigue stress. This can also be viewed as brittleness index of a strand of the conductor.

4. EFFECT OF MECHANICAL PARAMETERS

4.1. The effect of mechanical parameter on the behaviour of transmission line conductors are described here under

4.1.1 The unit weight of conductor has a direct effect on the Sag & Tension. It causes vertical load on the tower. Higher weight reduces the swing of the conductor in midspan but wind force increases.

4.1.2 Overall diameter of the conductor attracts wind force when it is strung on the towers. The drum on which the conductor is wound is sized considering the diameter and unit weight of the conductor. The hardware fittings also depend upon the diameter of the conductor.

4.1.3 Cross–sectional area of the conductor has a direct relation with the current carrying capacity. Cross–sectional area is also responsible for carrying the stress due to the Tension of the conductor. While working out Sag & Tension at different temperatures and wind pressure, the estimation of stress is very important.

Basic Equations

We have,

$G = L^2 \delta^2 q^2 E / 24$ .... (1)

Where,

G = variable operator

E = Modulus of elasticity

δ = Density of conductor = w/A (Kg /M/M²)

w = Weight of conductor per meter

A = Area of conductor M²

$(q)^2 = 1 + (p / w)^2$; (q = Resultant load)

p = Wind Force (Kg) = (P X D) where D = Diameter & P = Wind Pressure

Further,

Also, $G = f^2 \{f - (k - \alpha tE)\}$... (2)

Where,

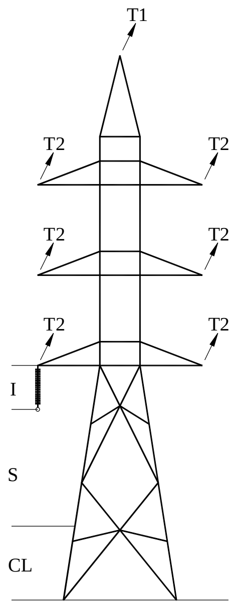
f = Stress on conductor (Kg/M^2),

k = Constant, t = Temperature (°C) and α = coefficient of Linear Expansion of the Conductor.

The value of sag, tension and factor of safety (FOS) are worked out for three wind conditions and three temperatures. The wind pressure is different for each of six wind zones of the country. The wind conditions are 0% wind, 36% wind and 100% wind. The three temperatures are minimum temperature (0^0C), everyday temperature (32^0C) and maximum temperature of conductor with the ambient is equal to 45^0C. Normally maximum temperature is 75^0C to 85^0C.

For calculating the sag, tension and FOS, starting condition is 32^0C temperature and 0% wind FOS = 4. UTS / FOS gives value of working stress **f**. Substituting value of **f** in the equation $G = L^2 \delta^2 q^2 E / 24 = f^2 \{f - (k - \alpha tE)$, we can find out a value of **k**. This value of **k** is common for all wind pressures and all temperatures. Thus, we can obtain value of stress **f** for any combination of wind and temperature. Further **f** x A = tension (**T**) where A = Cross sectional area of the conductor. Now sag (**S**) = $WL^2 / 8T$ and FOS = UTS/T. Therefore, we can find out sag, tension and FOS for all the wind pressures and all the temperatures.

4.1.4 The sag and tension calculations help in designing the line supports (towers). The sag at 0% wind (no wind) and maximum temperature will be maximum. The bottom cross arm of tower shall be at an appropriate height to take care of this maximum sag. The tension at 36% wind and 0^0C temperature or 100% wind at 32^0C temperature, whichever is higher, shall be considered for the strength of tower as show below

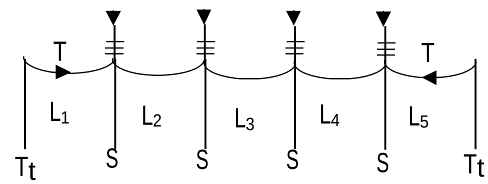


Where I = Insulator String length (Fixed)
S = Maximum Sag
CL = Clearance above ground (Fixed)
T_1 = Tension of ground wire
T_2 = Tension of conductor

Thus, the sag-tension calculation helps in designing the support (tower) structures.

4.1.5 Ruling span is very important for working out Sag & Tensions at different wind pressure and different temperature. There are different types of spans in design of transmission lines support, which are as under

- Normal Span–This is considered for design of support with reference to Sag & Tension.
- Wind Span–This is considered to take the effect of wind on conductor. It is normally 1.1 times the normal span.
- Weight Span–This is considered for the maximum weight of the conductor over longer tower spotting. It is normally1.5 to 2.0 times the normal span based on the reliability requirement of the tower and the line.
- Equivalent Span–This is a fictitious span considered for preparing the stringing charts between two tension locations



T_t= Tension Tower, S=Suspension Tower, L_1/L_2 etc. are the spans, T is a tension of conductor.

The equivalent span is worked out using following equation.

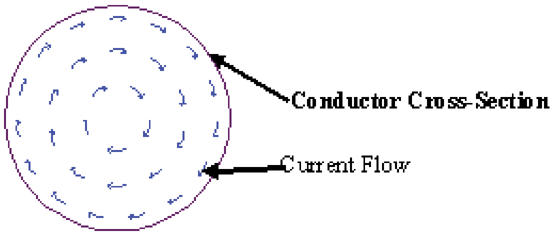
$$L_{eq} = \sqrt{\frac{L_1{}^3+L_2{}^3+L_3{}^3+L_4{}^3+L_5{}^3}{L_1+L_2+L_3+L_{14}+L_5}}$$

It is pertinent to note that the tension of conductor between two tension towers will be common for all the spans whereas the sag in individual span will be worked out on the basis of individual span.

5. EFFECT OF ELECTRICAL PARAMETERS ON THE CONDUCTORS AND LINE

5.1. The effect of electrical parameters on the conductor and line design are described below

5.1.1. Skin Effect–The tendency of the current to flow through the outer periphery is called a 'Skin Effect'. This is for the simple reason that in the outer periphery the area of conductor is larger and current always tries to take a path of least resistance.



The stranded conductors help in reducing the skin effect as the diameter of individual strand is very less and there is practically no scope for skin effect. Stranding of the conductor also helps in providing flexibility in the conductor for winding on the drum and in stringing.

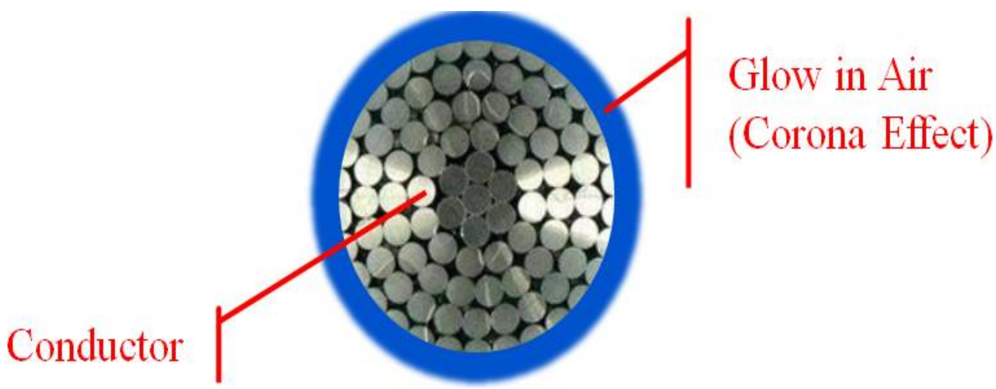
5.1.2. While carrying current at Extra High Voltage (EHV), the conductor has a tendency to ionize the surrounding air.

When the humidity is maximum the process of ionization of air becomes much significant. This phenomenon is called "Corona". Due to the corona the conductor surface is affected. New conductor surface experience less corona. As the conductor ages the corona becomes predominant.

The inception of corona is as a violate glow all along the conductor length. Corona is associated with hissing noise as well as production of ozone gas.

Just before monsoon when the humidity is at its peak, the corona becomes visible.

The conductors used for voltages above 220kV are also tested for corona.



The power loss due to corona is calculated by the formula

P = 242.2 (f+25) √ r (v-vc)2 x 10-5 kW/kM/phase

δ d

Where, f = supply frequency in Hz.

V = phase-neutral voltage (rms)

Vc = disruptive voltage (rms) per phase = mogo δ r log d kV/phase

Where,

mo = 1 for polished conductors.

= 0.98 to 0.92 for dirty conductor.

= 0.87 to 0.8 for stranded Conductor.

5.1.3. The inductance L of the conductor results into an inductive reactance which is worked out by an equation as follows:

$X_L = 2\pi fL$

where X_L is inductive reactance in Ohms,

f = frequency in Hz &

L= Inductance in Henri

The inductive reactance causes reduction in power factor cosφ

5.1.4. The capacitance C of the conductor results into a capacitive reactance which is worked out by an equation as follows

$X_c = \frac{1}{2\pi fc}$

Where X_c = Capacitive reactance in Ohms

f = frequency in Hz

c = capacitance in Farad

The capacitive reactance causes increase in power factor cosφ

6. NEW CENERATION CONDUCTORS

6.1. Due to the limitations of operations up to 90⁰C, the ACSR conductors are now being replaced by new generation conductors which operate at the temperatures beyond 90⁰C and even up to 250⁰C. This is possible only because of metallu-rgical changes in the structure of the conductors. They include Trapezoid shaping of Aluminium strands, Annealing of Aluminium strands, Aluminium cladding of steel core, use of INVAR core, use of carbon core etc.

6.2. The New generation conductors include the following

- Aluminium Alloy Conductor Steel Reinforced (AACSR)
- Aluminium Conductor Alloy Reinforced (ACAR)
- Trapezoidal Aluminium Strands with Steel Core (TASC)
- Thermal resistant Aluminium Alloy Conductor Steel Reinforced (TACSR)
- Aluminium Conductor Steel Supported (ACSS)
- Gap type Thermal resistant Aluminium conductor with Steel Reinforcement (GZTACSR)
- Super Thermal Alloy conductor with INVAR reinforcement (STACIR)
- Aluminium Conductor Composite Core (ACCC)

6.3. New generation conductors find good application for new lines and for up–rating (increasing Ampacity) and or up-gradation (increasing Voltage Level) of existing lines. The ACCC and ACSS conductors are much suitable for up–rating and or up-gradation of existing transmission network. The other type of New Generation Conductors finds their place in New Transmission Lines, this includes evacuation lines for solar/wind power and also from super thermal power stations.

6.4. The table below gives comparison of mechanical, electrical and thermal capabilities of various conductors. It can be seen that the new generation conductors can operate at very high temperatures.

Technical Comparison for ACSR Zebra & its equivalent Conductors - WIND ZONE 4													
Type of Cond.	Cross Sect. Area (mm^2)	Con. Dia. (mm)	Modulus Of Elasticity (kg/cm^2)	Co-eff. of Linear Exp. (/°C)	Weight (kg /km)	UTS (kgf)	AC Ress. ohms/km	Max. Temp. (°C)	Volt Level (kV)	Current carrying capacity	Sag at Maximum Operating Temp. (°C) & 0% wind	Tension at 32°C & 100% wind	Revenue generated in INR 4/unit
ACSR Zebra	484.50	28.62	725500.00	$19.4*10^{-6}$	1621.00	13283.38	0.08479	75	220	562.33	9.26	8052.54	6199276800
TACSR	467.00	28.62	725500.00	$11.5*10^{-6}$	1621.00	14290.52	0.08668	150	220	1241.18	10.20	8050.29	13648220160
STACIR	446.63	27.60	713557 & 1580020.38	$16*10^{-6}$ & $3.7*10^{-6}$	1616.00	14290.52	0.09594	210	220	1454.41	8.89	8054.79	15982900320
ACSS (ZEBRA)	484.50	28.62	702344 & 2110091.74	$18*10^{-6}$ & $11.5*10^{-6}$	1621.00	13221.20	0.08051	210	220	1660.90	11.95	8053.46	18257416800
ACCC Hamburg	613.80	28.62	1179408.76 & 636085.6269	$1.61*10^{-6}$ & $19.1*10^{-6}$	1646.40	16442.41	0.06360	175	220	1602.63	9.76	8054.04	17602273920
ECO	583.02	28.62	662589.19	$23*10^{-6}$	1608.00	13781.86	0.06309	95	220	952.50	10.75	8051.74	10470477600
ACCC Kolkata	630.69	28.62	1144750.25 & 655453.61	$1.61*10^{-6}$ & $18.7*10^{-6}$	1606.00	17614.68	0.06629	175	220	1570.43	9.84	8052.59	17251873920
GAP	567.5	29	2098878.69 & 758409.75	$20.2*10^{-6}$ & $11.5*10^{-6}$	1856	15586.14	0.07012	210	220	1718.82	12.77	8049.82	18890239200
ACSS-TW	588.5	28.62	717227.31 & 2089704.38	$19.46*10^{-6}$ & $9.1*10^{-6}$	1893	10499.49	0.08051	210	220	1600.90	11.90	8054.27	17594039520
AL-59 (61/3.18)	484.5	28.62	560843.92	$23*10^{-6}$	1704	12368.00	0.07534	95	220	874.41	9.73	8051.44	9629517600
AAAC (61/3.19)	488	28.7	693100.00	$23*10^{-6}$	1345	13663.61	0.08498	95	220	826.02	10.03	8054.83	9103917600
ACCR	484	28.6	1193068.00	$16.5*10^{-6}$ & $6.3*10^{-6}$	1357.6	14323.30	0.08112	210	220	1594.62	11.45	5128.75	17523959520

Note: The values of modulas of electicity indicated in column 4 for STACIR, ACSS, ACCC, GAP and ACCR conductors are respectively for below and above knee point temperatures.

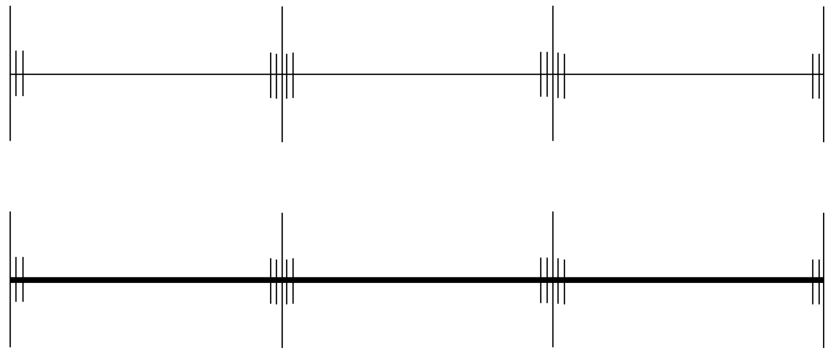
7. CASE STUDIES

1. 66kV line updated to 132kV for Torrent Power Ahmadabad

As a part of up-gradation of existing power system Torrent Power Ahmedabad decided to convert one of the two double circuit lines from 66kV to 132kV from Naroda substation to Nicol substation. The line was upgraded to 132kV and replacement of ACSR Dog conductor to ACCC Casablanca conductor. The 66kV D/C line which was carrying 260Amp is now able to carry 1050 Amp. The tower on the right side is 66kV D/C and one on the left is tower modified from 66kV D/C to 132kV D/C. This is possible only due to the metallurgical changes in the design of conductors

2. 220kV Borivali substation change in ampacity of existing Bus

In Borivali 220kV substation the existing bus was having twin ACSR Moose conductor. The capacity of this Bus was 1500Amps (750Amps / Conductor). Due to installation of GIS equipment the capacity of the Bus needed to be augmented to 3000Amps. Using Quad ACSR moose conductor would mean change in the existing structures and gantry column foundations. Since the substation in north Mumbai cannot afford longer shutdowns, various options were tried out and ultimately it was decided to use twin ACSS Curlew conductor which delivers 3200Amps (1600Amps per conductor) at 160^0 C.



The ACSS Curlew Conductor has same mechanical properties that of the ACSR moose conductor and therefore no change in structure and foundation was required. The entire work was completed within couple of short duration shutdown.

8. CONCLUSION

8.1. The metallurgical, mechanical and electrical parameters of conductor has a big influence on the electrical and mechanical design of EHV transmission lines.

8.2. The changes of metallurgical structure of the transmission line conductor have a large influence on the electrical & structural design of the line and also on the performance of line.

About Author:

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Graduated in Electrical Engineering from MS University, Vadodara in 1971. He joined Gujarat Electricity Board in 1972 as a Junior Engineering and retired as a Chief Engineer (Transmission) in 2006. During his tenure of 34 years he worked in Distribution, Generation and Transmission Department. Most of his tenure was in Transmission department. He is a member of Bureau of Indian Standards (BIS) and Central Board of Irrigation and Power (CBIP) for Transmission line and Substation related committees.

He has received several Awards for R&D and contribution to the Transmission Segment. At present he is a Managing Director of M/s Takalkar Power Engineers and Consultants Pvt. Ltd. Vadodara. The firm is offering services of Electrical, Civil & Structural Engineering Designs, Energy Management, Project Monitoring and Energy Audit.

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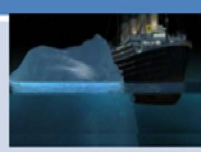
Advanced Material for Ultra Mega Power Plants Boiler & Turbine

Mr. Dinnanath Akela
Reliance Industries Ltd.

Learning Opportunity

- Materials classification
- Classification of Iron Metallurgy
- Iron Carbon Equilibrium Diagram
- Challenges for Boiler Tubes Metallurgy Selection
- Effect of chemical Composition as Ni, Co, V, Ph, Silica, Cr, C, Ti, Mo & Mn.
- Boiler Materials
- Basic Metallurgy of various Pressure parts of boilers
- Pressure and temperature selection as per IBR 1950
- Calculation For Minimum Thk (IBR 1950 Reg 338)
- Materials Testing
- Creep Cycle
- Fatigue failure
- PMI
- Correct Step for Post-Mortem of Tube Failures
- Case Studies
- FAQ

Lessons learnt world over

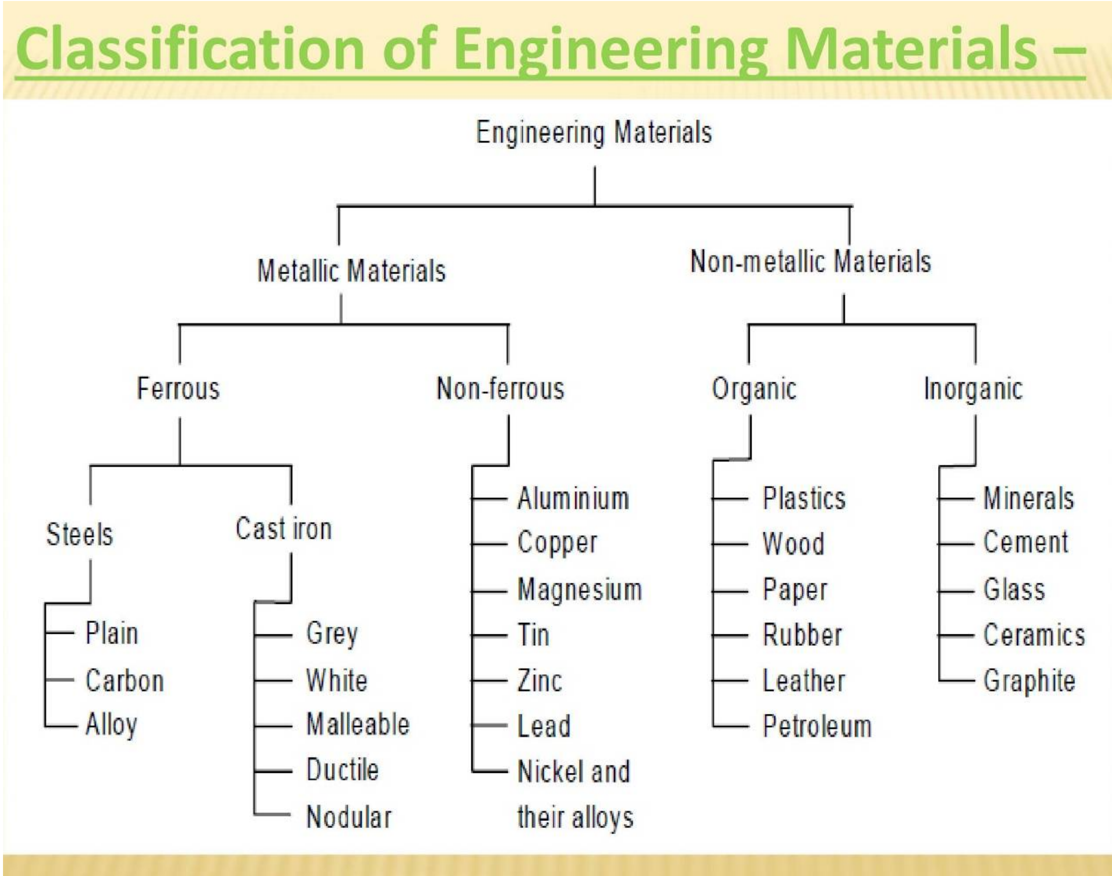
Failure	Year		Reason for failure	Life assessment developments
Titanic	1912		Ship hits iceberg and watertight compartments rupture	• Improvement in steel grade • Safety procedures established for lifeboats • Warning systems established for icebergs
Molasses tank failures (The Boston Molasses Disaster of 1919)	1919, 1973		Brittle fracture of the tank as a result of poor ductility and higher loads	• Design codes for storage tanks developed • Consideration given to causes for brittle fracture
Tacoma bridge failure	1940		Aerodynamic instability and failure caused by wind vortices and bridge design	• Sophisticated analytical models developed for resonance • Bridge design changed to account for aerodynamic conditions

Lessons learnt world over

Failure	Year		Reason for failure	Life assessment developments
World war II Liberty ships	1942 - 1952		1289 of the 4694 warships suffered brittle fracture or structure failure at the welded steel joints.	1289 of the 4694 warships suffered brittle fracture or structure failure at the welded steel joints
Comet aircraft failures	1950s		Fatigue crack initiation in pressurized skins due to high gross stresses and stress concentration effects from geometric features	• Development of fatigue 'safe-life' approach • Evaluation of the effects of geometry and notches on fatigue behaviour • Evaluation of the effects of stiffeners on stress distribution • Establishment of aircraft structural integrity program (ASIP) in 1958
Seam welded high energy piping failures	1986-2000		Cavitation and creep voids in welds resulting in catastrophic high-energy rupture	• Development of elevated-temperature life assessment techniques for cavitation and creep failure

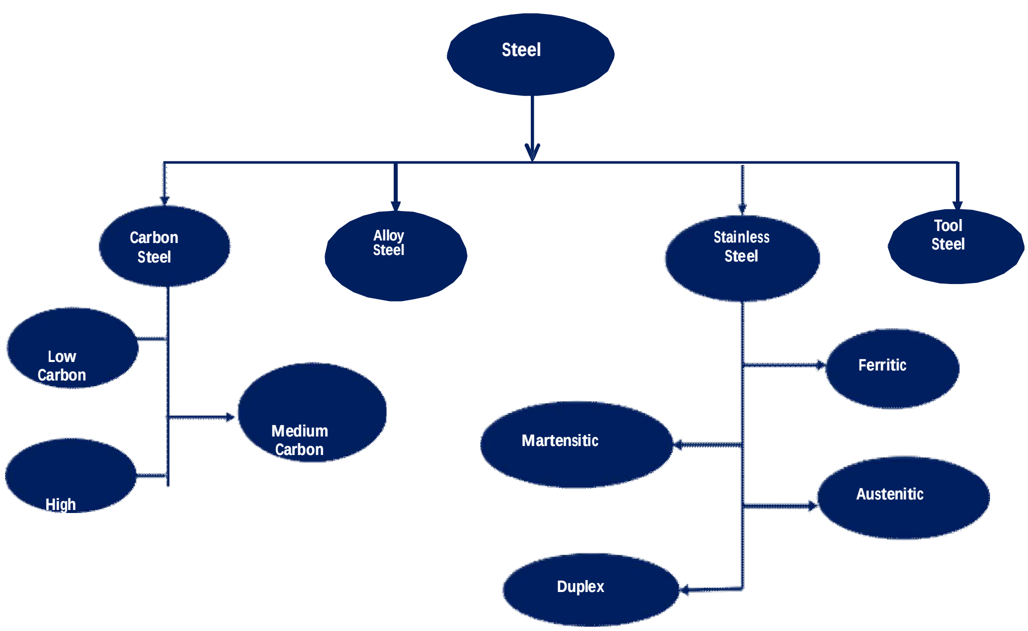
Metallurgy

The behavior of metallic elements, their inter-metallic compounds, and their mixtures, which are called alloys. Metallurgy encompasses both the science and the technology of metals:



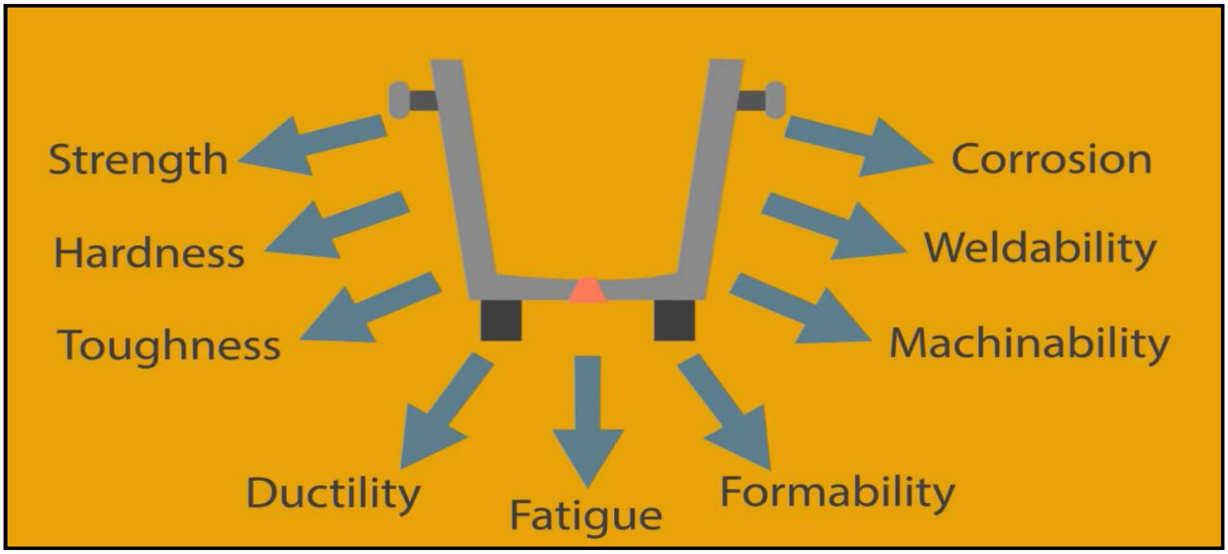
Classification of Engineering Materials:

Type of Steel



Classification of Carbon Steel

- Mild/Low Steel – Carbon Content <0.25%
- Medium Carbon Steel – Carbon Content 0.25%- 0.6%
- High Carbon Steel – Carbon Content 0.6%- 1.5%



Manufacturing Process of Tubes /Headers / Drum of Boilers Mechanical Tests Boiler Pressure Parts

Mechanical Tests for Boiler Pressure Parts	Type of tests
Tubes	Tensile Test, flattening test, Flaring test, & Hardness Test
Pipes	Tensile Test, Flattening or bend test & Hardness Test
Fittings & Forgings	Tensile Test, bend test & Hardness Test
Plates	Tensile Test, bend test & Hardness Test

Manufacturing Process

Key Requirements for Tubes

(SA213 – T11/ T22/ T91/ T92)

- Manufacturing method: hot/cold finished
- Chemical test (ladle and product)
- Heat treatment
- NDE requirement: ET (E309), UT (E213), FLE (E570),
- Hydro Test
- Flattening Test**
- Flaring Test **
- Tensile test **

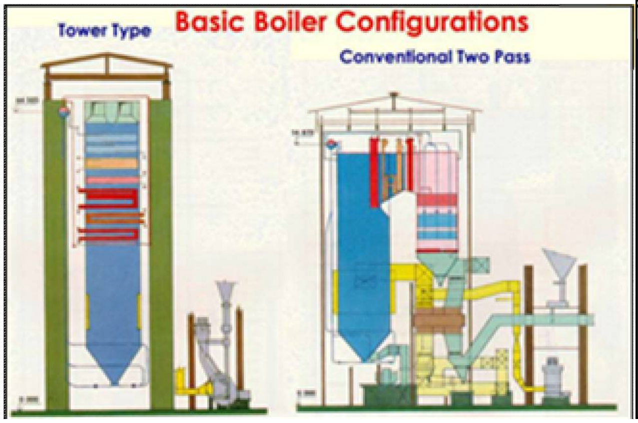
- Hardness test **
- Visual and Dimension Inspection
- Product marking
- IBR certification and MTC

**Testing frequency: made on minimum 2 tubes for first 100 and 1 per 100 or part thereof for over 100 numbers

Key Requirements for plates
(SA387-12/ 22/ 91, SA515 & SA516 – 60/65/70)

- Chemical test (ladle and product)
- Heat treatment
- NDE requirement: UT (SA578 LB / LC)
- Tensile test **
- Bend test **
- Visual and Dimension Inspection
- Product marking
- IBR certification and MTC

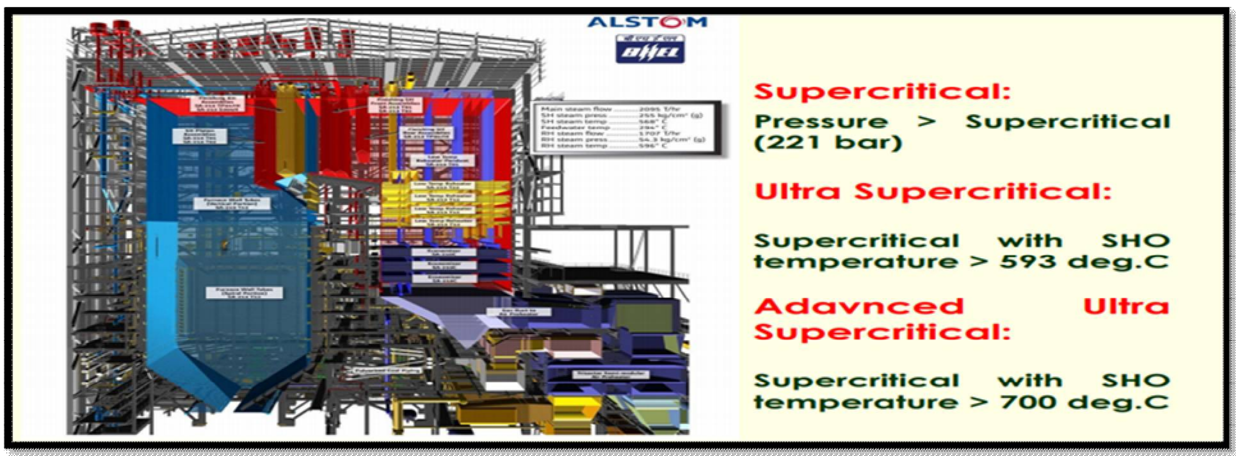
**1 test each shall be cut from each mother plate



Boiler Parameters

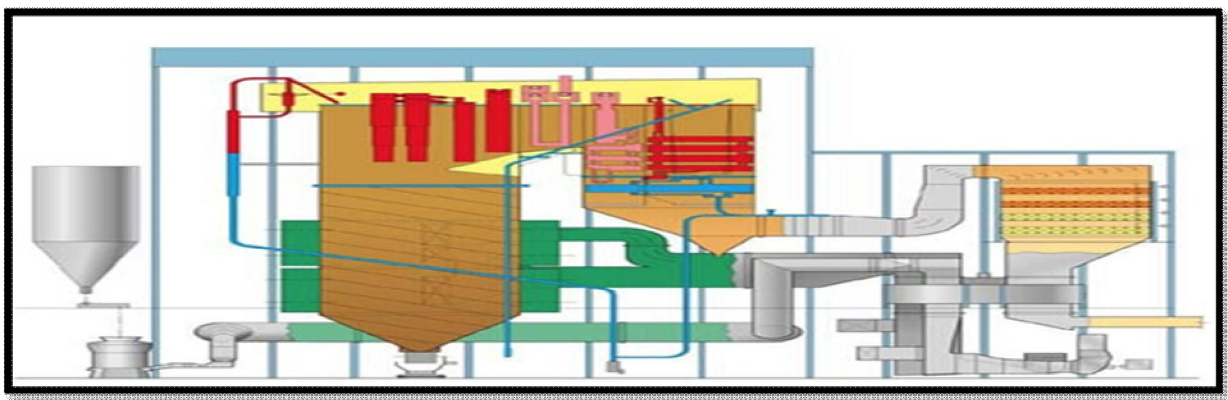
DESCRIPTION		LOAD				
		HP Heater In				HPH Out
		MCR	NCR		CL . . %	NCR
MAIN STEAM						
Steam flow at SH Outlet	t / h					
Pressure at SH Outlet	kg / cm² (g)					
Temperature at SH Outlet	°C					
REHEAT STEAM						
Steam flow at RH Outlet	t / h					
Pressure at HPT Outlet / RH Inlet	kg / cm² (g)					
Temperature at HPT Outlet / RH Inlet	°C					
Pressure drop allowed CRHL / RH / HRHL	kg / cm²					
Pressure at RH Outlet / IPT Inlet	kg / cm² (g)					
Temperature at RH Outlet / IPT Inlet	°C					
FEED WATER						
Feed Water Temperature	°C					

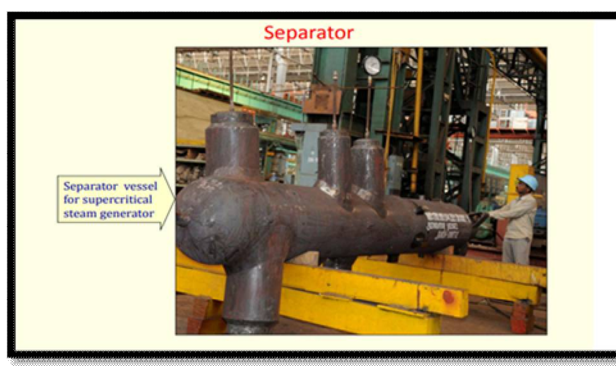
Boiler Classification

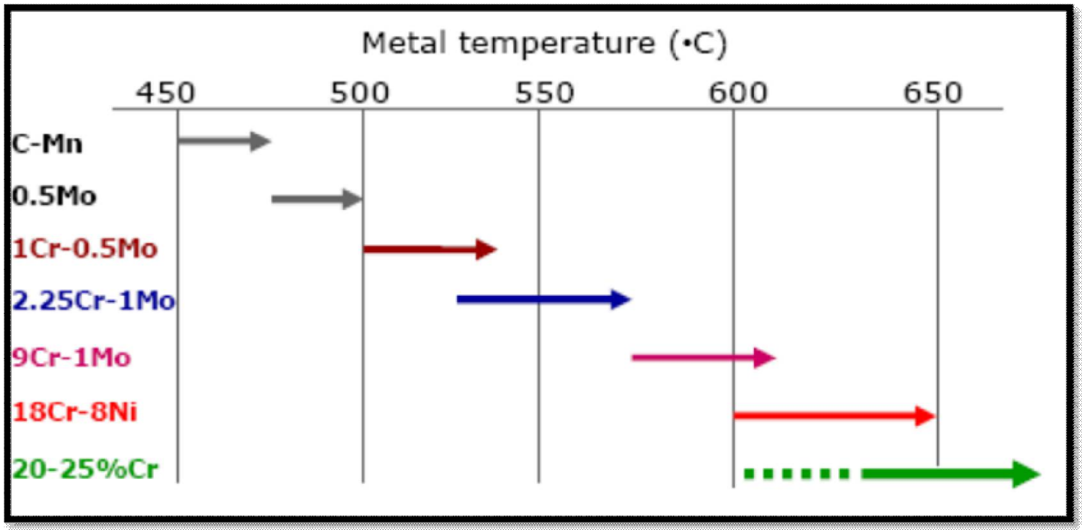


Spiral Wound Furnace For Super Critical Boiler

Spiral Wound Furnace For Super Critical Boilers



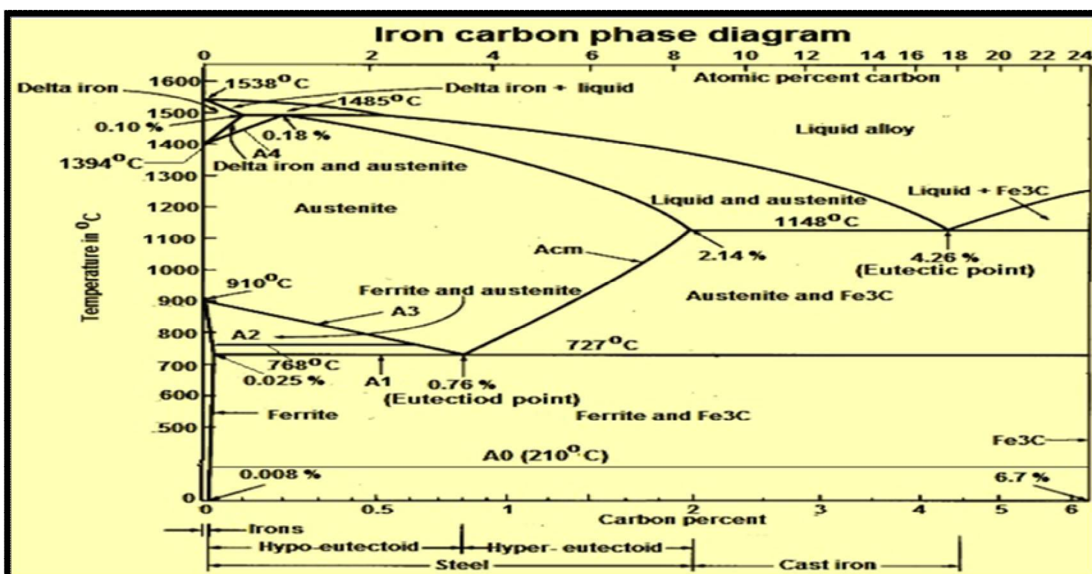




History of Boiler Metallurgy Developments

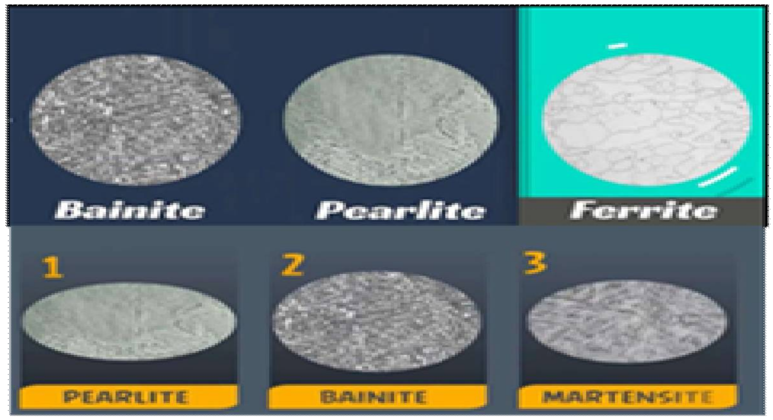
- Centre for Metallurgical Research, Belgium Developed “Super 9 Chrome” – (9Cr-2Mo): Year 1950
- V & M (France) rolled the first tubes for Super Heater application named EM12: Year 1964
- Limitation: (a) Low impact strength (b) Use in thin section
- X20 (12Cr) was developed by German Steel Maker [X20CrMoV21 1]: Year 1960
- Limitation: (a) Poor weld ability (b) Low creep strength (520°C)
- US Department of Energy (Liquid Metal Fast Beeder Reactor Program) along with ORNL & C-E developed Modified 9Cr-1Mo Steel: Year 1974
- ASME recognized SA213 T91: Year 1983
- ASME recognized SA213 P91: Year 1984

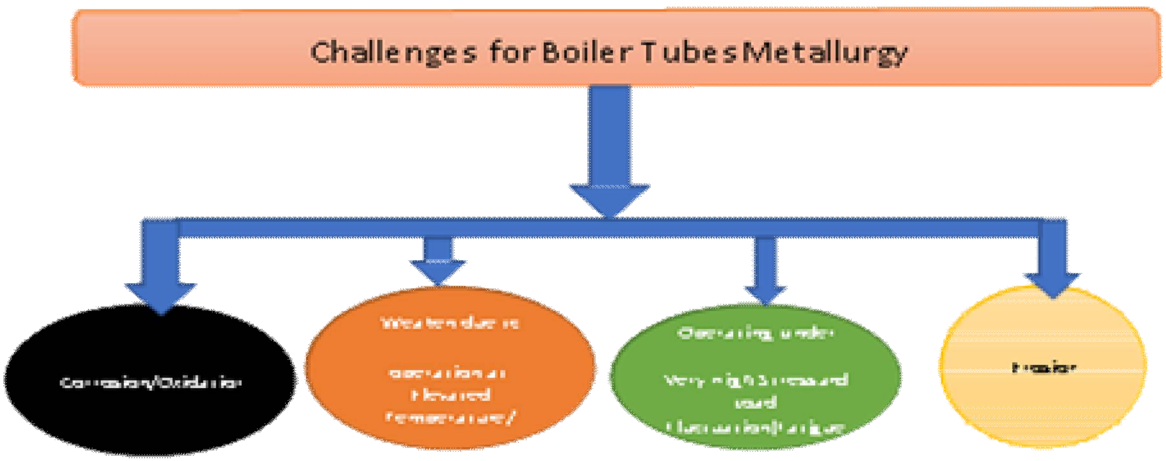
Iron Carbon Equilibrium Diagram



Details about Ferrite / Pearlite / Cementite & Austenite

- Ferrite
- Pearlite
- Cementite
- Austenite
  - Bainitic





Effect of Alloying Elements of Boiler Tube Metallurgy

Sl No.	Alloying Material	Symbol	Properties
1	Manganese	Mn	Improves strength and hardness
2	Phosphorus	P	Improves strength and hardness
3	Nickel	Ni	Improves strength and hardness
4	Sulphur	S	Improves machinability
5	Chromium	Cr	Scale and heat resistance
6	Silicon	Si	Scale resistance
7	Aluminium	Al	Scale resistance
8	Molybdenum	Mo	Improve heat and creep resistance
9	Vanadium	V	Improve heat and creep resistance
10	Tungsten	W	Improve heat and creep resistance
11	Titanium	Ti	Prevents intercrystalline corrosion
12	Niobium	Nb	Prevents intercrystalline corrosion
13	Boron	B	Improves refractoriness

Conventional Boiler Materials

Area of Application	Material type	Typical spec. for Plates, Tubes, Pipes	Upper limit Temp. ^{0}C (Heat Absorbing Surface)	Guiding Reason for Upper Limit
Drum	C Steel/ Low Alloy Steel	SA299	425	
Waterwalls, Economiser	C Steel	SA192, SA210, SA106	425	Graphitisation
Superheater and Reheater	C ½ Mo steel	A209 T1	465	Graphitisation
	1Cr ½ Mo	SA213T11, SA335P11	565	Oxidation/corrosion, Flue gas
	2 ¼ Cr 1Mo	SA213T22, SA335P22	580	Oxidation/corrosion, Flue gas
	18 Cr 8 Ni	SA213 TP304 H	704	
	18 Cr 10 Ni Cb	SA213 TP347 H	704	
	Modified 9Cr	SA213 T91, T92 SA335 P91, P92	650	ASME code
	12%Cr	X20CrMoV12 1	700	German Code

Materials used in various Pressure Parts of Subcritical Boilers

Area of application	Material	ASME specification	
		Tubes	Pipes
Drum	Carbon steel / Low Alloy steel	-	SA 299
Water walls, Economizer	Carbon Steel	SA192 SA210 Gr.A1 SA210 Gr.C	SA106 Gr.B SA106 Gr.C
SH and RH	1 ¼ Cr ½ Mo	SA213 T11	SA335 P11
	2¼ Cr 1 Mo	SA213 T22	SA335 P22
	9 Cr 1 Mo ¼V	SA213 T91	SA335 P91
	18 Cr 8 Ni	SA213 TP304 H	-
	18 Cr 10 Ni Cb	SA213 TP347 H	-

Design Criteria for Boiler Materials:

selection –As Per IBR 1950 Reg 338

Selecting the process material to be used during a pressure parts selection is critical in order to maximum the reliability and life of the boiler components.

Design criteria

1. Material metal temperature limits
2. Minimum wall thickness or tube / plate thickness

Material wall thickness required to operate at design pressure and temperature

Allowable Stress values are chosen upon the material type and the Average material metal temperature.

Step 1: Design Pressure (DP) and Deign Temperature (DT)

Step 2: Verify the grade wise metal temperature limit as per IBR

Step 3: Take the allowable stress value as per Section II Part D of the ASME BPVC

Step 4: Calculate the Minimum design Thickness Value.

Allowable Temperature as per IBR & ASME :

Material	Max. Temperature Limits
SA210 Gr.C	454 Deg. C
SA213 T11	648 Deg. C
SA213 T22	648 Deg. C
SA213 T91	648 Deg. C
SA213 T22	648 Deg. C
SA106 Gr.C	454 Deg. C
SA335 P11	648 Deg. C
SA335 P22	648 Deg. C
SA335 P91	648 Deg. C

Material	Max. Temperature Limits
SA387-12	649 Deg. C
SA387 - 22	649 Deg. C
SA387 - 91	649 Deg. C
SA515 - 60	538 Deg. C
SA515 - 65	538 Deg. C
SA515 - 70	538 Deg. C
SA516 - 60	454 Deg. C
SA516 - 65	454 Deg. C
SA516 - 70	454 Deg. C
SA240 TP304	816 Deg. C

BET Minimum Thk Calculation

Standard	:	ASME SA 210 / ASTM A210
Outer Dimensions	:	12.7mm-114.3mm
Wall Thickness	:	0.8mm-15mm
Length	:	5-25mm
Grade	:	A1

GR.A1 A210 Heat Exchanger Tubes Chemical Composition :

Grade	C(Max)	Mn	Si(Min)
A1	0.27	Max 0.93	0.10

ASME SA210 Standard Pipes Mechanical Properties :

Grade	Tensile Strength(Mpa)	Yield Strength(Mpa)
A1	≥415	≥255

- AS Per IBR 1950 Reg 338 for Allowable Minimum Tek for Bed Evaporative Tubes would be
- MAWP = 2f(t-c)/D-t+C
- where D= OD of BET
- t= Minimum allowable thk
- f = Allowable tensile strength for Tube Materials SA210Gr A1 for Temperature <454 Degree C
- C= 0 (MAWP > 70 kg/cm^2)

Calculation For Minimum Thk (IBR 1950 Reg. 338)

Permissible working stress for tubes:- For temperatures at or below 454 °C,

$$\frac{T.S.}{2.7} \text{ or } \frac{Et}{1.5} \text{ whichever is lower.}$$

For temperature above 454 °C,

$$\frac{Sr}{1.5} \text{ or } Sc \text{ whichever is lower.}$$

where,

T.S. = Minimum tensile strength of the material at room temperature.
Et = Yield point (0.2% proof stress) at working metal temperature 't'.
Sr = the average stress to produce rupture in 100,000 hours and in no case more than 1.33 times the lowest stress to produce rupture at the working metal temperature.
Sc = the average stress to produce an elongation of 1% (creep) in 100,000 hours, at the working metal temp.

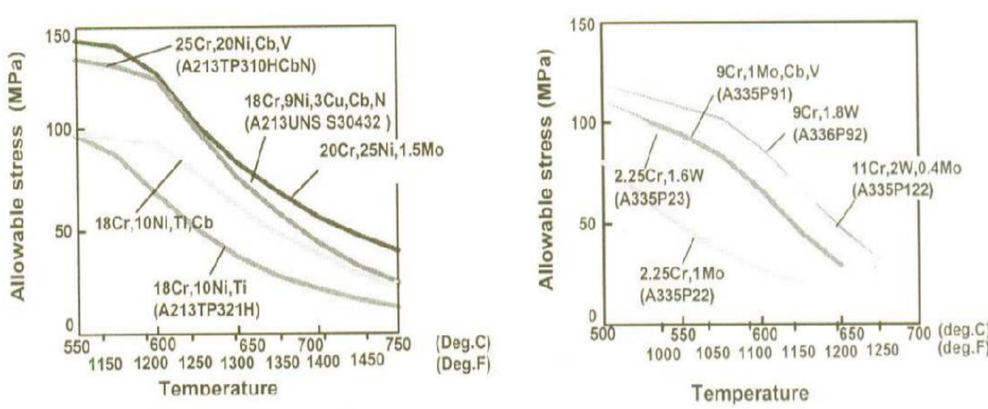
MAWP = 2f(t-c)/D-t+c
92= 2x1537t/51-t
t=1.488mm
As per IBR we have taken 12.5 % corrosion allowance then,
Minimum BET Thk would be =1.674mm

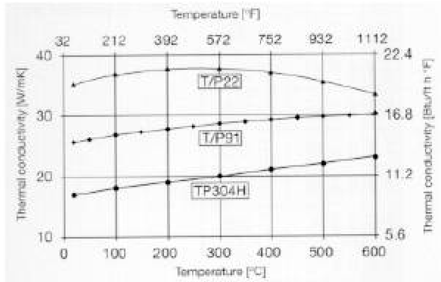
Item	Section	Material Specification (ASME)
Water Wall	Tubing	SA 213-T22
Superheater	Header & Piping	SA 335-T12
		SA 335-T91
	Tubing	SA 213-T12
		SA 213-T23
		SA 213-T91
		Super 304 H
Reheater	Header & Piping	SA 106-C
		SA 335-P12
		SA 335-P91
	Tubing	SA210 Gr C
		SA 213-T12
		SA 213-T23
		SA 213-T91
		Super 304 H
Economiser	Header & Piping	SA 106-C
	Tubing	SA210 C
Separator storage tank		SA302 C

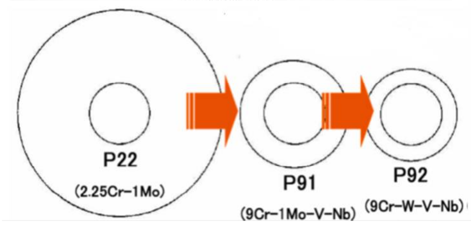
ALLOWABLE MAXIMUM FLUID TEMPERATURES AND METAL TEMPERATURES FOR DIFFERENT MATERIALS

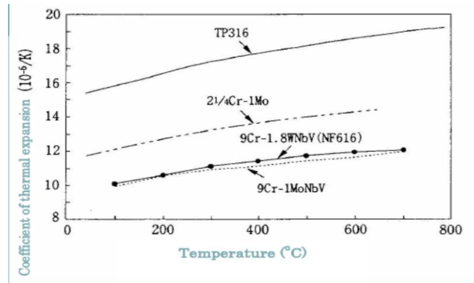
Material	ASME Alloy	Oxidation Limit, Deg. C	IBR Allowable, Deg. C
Carbon steel	SA -210 Gr A1	454	454
	SA-106-C/B	427	
	SA -299 (drums)		
	SA-515, 70		
1 Cr-1/2 Mo	SA-213, T12	552	649
	SA-335, P12		
1-1/4 Cr-1/2 Mo	SA-213, T11		
	SA-335, P11		
2-1/4 Cr-1Mo	SA-213, T22	593	
	SA-335, P22		
2-1/4 Cr-1.6W-V-Cb	SA-213, T23		
	SA-335, P23		
9 Cr-1 Mo. V	SA-213, T91	649	
	SA-335, P91		
9 Cr-2W	SA-213, T92		
	SA-335, P92		
18 Cr-10 Ni Cb	SA-213, TP347H	740	816
18 Cr-9 Ni -3Cu-Cb-N	SA-213, Super 304H		

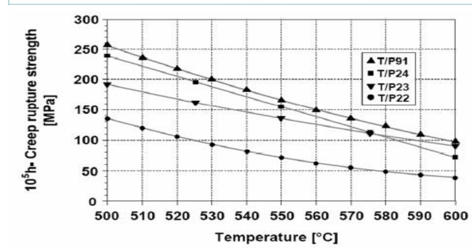
Comparison of allowable stresses between conventional and advanced materials











New Materials for Ultra Super Critical Boiler Materials

- This increased efficiency is expected to be achieved principally through the use of advanced ultra-supercritical (A-USC) steam conditions up to 760°C (1400°F) and 35 MPa (5000 psi).
- A limiting factor to achieving these higher temperatures and pressures for future A-USC plants are the materials of construction.

	Material	Average Composition	Application (1)		
			SC	USC	A-USC
CrMo steels	Gr. 11	1¼ Cr-Mo	WW		
	Gr. 22	2¼ Cr-Mo	P, WW	WW	
Creep-strength enhanced ferritic (CSEF) steels	Gr. 23	2¼ Cr-1.5W-V		WW	WW
	Gr. 91	9Cr-Mo-V-Nb	P, SH/RH	P, SH/RH	WW
	Gr. 122	10.5Cr-W-Mo-V-Nb	P	P	WW
	Gr. 92	9Cr-2W-V-Nb	P	P	WW
Austenitic stainless steels	304H	18Cr-8Ni	SH/RH		
	347H	18Cr-10Ni-Nb	SH/RH		
Advanced austenitic stainless steels	347HFG	18Cr-10Ni-Nb (2)	SH/RH	SH/RH	
	Super 304H	18Cr-10Ni-Nb-Cu	SH/RH	SH/RH	
	NF709	20Cr-25Ni-Mo-Nb-B		SH/RH	SH/RH
	HR3C	25Cr-20Ni-Nb		SH/RH	SH/RH
	Sanicro 25	22Cr-25Ni-4W-3Cu-Co		SH/RH	SH/RH
Nickel-based alloys (3)	IN617	22Cr-9Mo-10Co			P, SH/RH
	Haynes 230	22Cr-14W-2Mo			P, SH/RH
	IN740	25Cr-20Co-Al-Ti-Nb			P, SH/RH
	Haynes 282	20Cr-10Co-8Mo-2Ti-Al-Fe			P, SH/RH

The boiler tubes are under high pressure and/or high-temperature conditions.

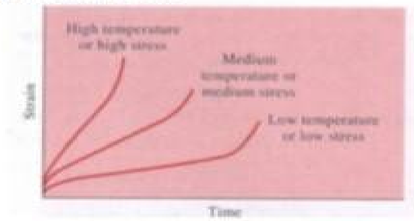
They are subject to potential degradation by a variety of mechanical and thermal stresses and environmental attack on both the fluid and fireside.

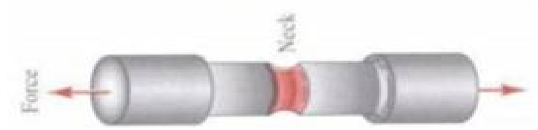
Mechanical components can fail due to creep, fatigue, erosion, and corrosion

Creep

Creep is a time-dependent deformation that takes place at elevated temperature under mechanical stresses.

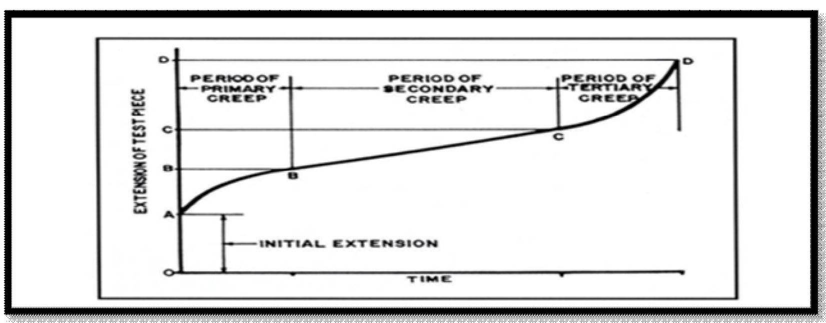
such failure results in overheating or overstressing the tube material beyond its capabilities for either a short-term or a long-term period.





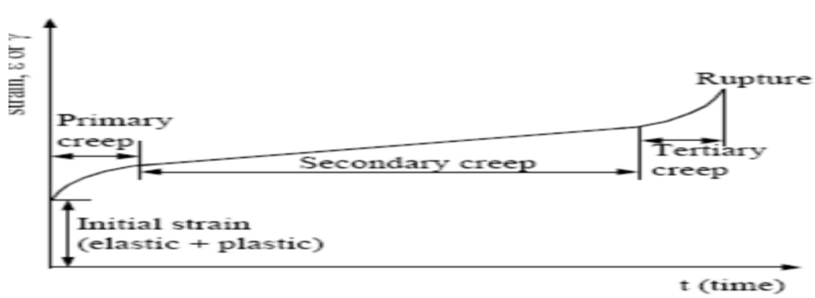
Creep failures are characterized by

- Bulging or blisters in the tube
- Thick-edged fractures often with very little obvious ductility
- Longitudinal "stress cracks" in either or both ID and OD oxide scales
- External or internal oxide-scale thicknesses that suggest higher-than-expected temperatures
- Intergranular voids and cracks in the microstructure



Creep stage and rupture

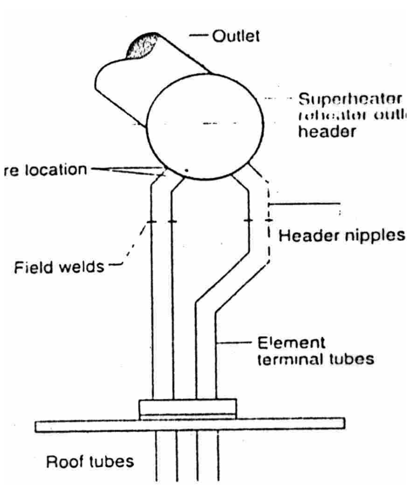
- Primary creep –start with a rapid rate and slow with the time
- Secondary cream creep –has relatively uniform rate
- Tertiary creep –it has an accelerated creep rate and terminated when the material breaks or rupture .it associated with both necking and formation of grain boundaries voids.
- creep in service is easily affected by change in condition of loading and temperature



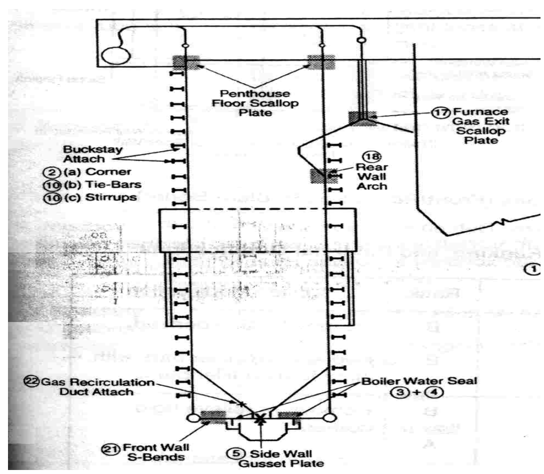
Fatigue failure

- Fatigue is a phenomenon of damage accumulation caused by cyclic or fluctuating stresses, which are caused by mechanical loads, flow-induced vibration.
- components are subjected to cyclic temperature and flow fluctuations restrict thermal expansion.
- Thermal fatigue is classified in two categories, corrosion fatigue and thermal fatigue.
- **Corrosion fatigue,** —the fluctuations in circulation of water in the boiler tube
- **Thermal fatigue:** frequent starts and stops
- Typically occurs at areas such as header ligaments, welded attachments, tube stub welds, circumferential external surface cracking of water wall tubes in supercritical units, and fabrication notches.

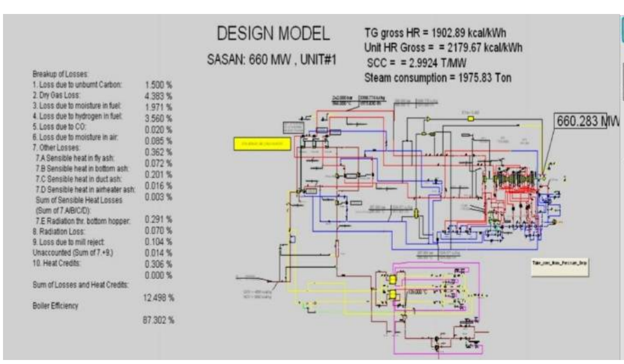


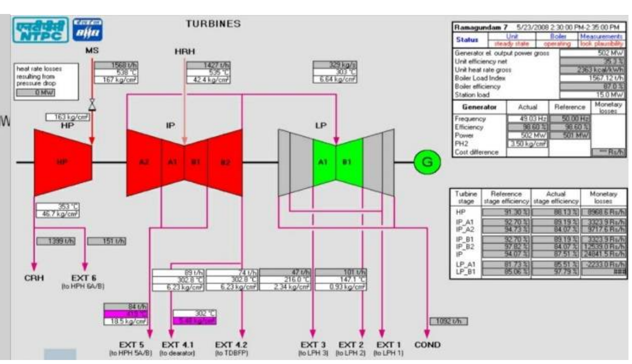


LOCATIONS OF THERMAL FATIGUE



LOCATIONS OF CORROSION FATIGUE





Testing of Materials after Tube Failures

Metallographic Test

Hardness Test(Vickers Hardness Test)

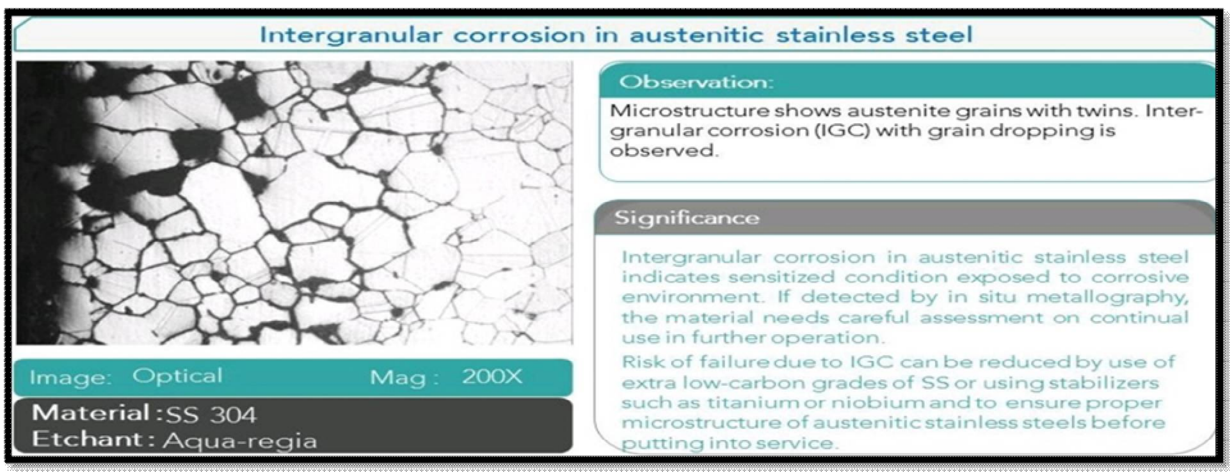
ESEM/EDS Analysis(Elemental Deposit Analysis)

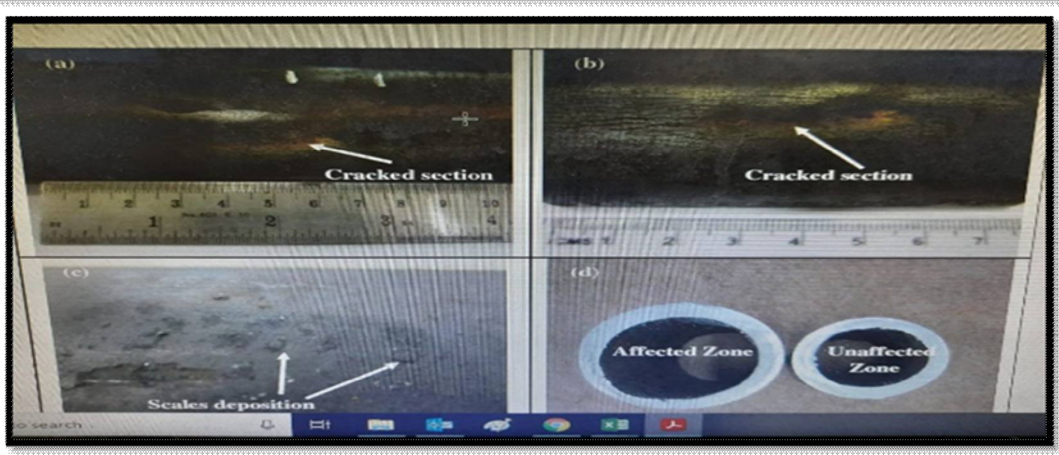
In-situ Metallography

- Definition
- Technique
- Process

Result of In-situ Metallography:

- It reveals about microstructure of failed tubes which having ferrite and pearlite grain structure and inclusion of carbon (Fe_3C)
- Inclusion of carbon in grain structure of ferrite and pearlite add cohesive forces and makes materials brittle
- it also revealed localized material lost from inner surface of the tube which is most likely due to internal corrosion.
- Metallographic examinations conclude on the failed tube from rupture side, its microstructures revealed about the overheating of the rupture tubes at failed locations





PMI

TABLE B-1
IDENTIFICATION ELEMENTS

Materials	Identification Elements	Materials	Identification Elements
Carbon steel	C [Note (1)], Si [Note (1)], Mo, Cu < 0.43, Ni < 0.43, Cr < 0.34, Mo < 0.13, (V + Cb) < 0.07, (Cr + Mo) < 0.32, (Cu + Ni + Cr + Mo) < 1.00	Alloy 20Cb-3	C [Note (1)], Cr, Ni, Mo, Cb, Cu
C-½Mo	Mo	Brass, admiralty	Sn
1 Cr-½ Mo	Cr, Mo	Brass, naval	Sn
1¼ Cr-½ Mo	Cr, Mo	Brass, aluminum	Zn, Al
2¼ Cr-Mo	Cr, Mo	90/10 Cu/Ni	Cu, Ni
5 Cr-½ Mo	Cr, Mo	70/30 Cu/Ni	Cu/Ni
7 Cr-½ Mo	Cr, Mo	Alloy 400	Ni, Cu
9 Cr-I Mo	Cr, Mo	AL-6XN	Cr, Ni, Mo
9Cr-1Mo-0.2V	Cr, Mo, V	Titanium Grades 1 and 2	Ti
12 Cr (Type 405/410SS)	C [Note (1)], Cr	Grade 12 Ti	Ti, Mo [Note (1)], Ni [Note (1)]
12 Cr (Type 410)	Cr	Grade 16 Ti	Ti, Pd [Note (1)]
17 Cr (Type 430)	Cr	Alloy 182	Ni, Cr
25 Cr (Type 446)	Cr	Alloy 600	Ni, Cr
304	Cr, Ni	Alloy 625	Ni, Cr, Mo, Cb, Ti
304L	C [Note (1)], Cr, Ni	Alloy 800	Ni, Cr, Al, Ti
304H	C [Note (1)], Cr, Ni	Alloy 825	Ni, Cr, Mo, Cu, Ti
309L	C [Note (1)], Cr, Ni	AISI 4140	C [Note (1)], Cr
309CbL	C [Note (1)], Cr, Ni, Cb	AISI 4340	C [Note (1)], Cr, Ni
310	Cr, Ni	Alloy 2205	Cr, Ni, Mo
316/317	Cr, Ni, Mo	Alloy 2507	Cr, Ni, Mo
316L/317L	C [Note (1)], Cr, Ni, Mo	3.5Ni, 5Ni, and 9Ni	Ni
321	Cr, Ni, Ti	Hastelloy C276	Ni, Cr, Mo, W
347	Cr, Ni, Cb	. . .	. . .

GENERAL NOTE: Percentages shall be within the limits specified in the appropriate standards/specifications.

Correct Step for Post-Mortem of Tube Failures

Premiliary Investigation Input & Background Study Sheet of 1500TPH PF Boiler

Customer Site/ Location: DNA 05.03.2021

Sr NO	Boiler Design Data:
A	Boiler Reg No:
	Boiler Make & Type
	BMCR Flow / Temp & Rated Pressure
	COD
	Fuel used
	Super Heaters Pressure & Temperature
	Re Heater Flow, Pressure & Temp
	Feed Water Inlet Temperature
	Boiler Heating Surface Area:

B — Current Tube Failure Details :

Tube sample/ Tube No	Location/Elevation	Nominal Dimention of Tube(ODxThk)	Measured Dimention	Grade of Steel /Alloy Steel

C — Operating Parameters of Service of Exposed Tube:

Tube sample/ Tube No	Designed Steam Temp Degree C	Operating Pressure	Length Of Service (Last light Up Time of Boiler) (hrs)	Zone/ Elevation	Flue Gas Temperature

C — Operating Parameters of Service of Exposed Tube:

Tube sample/ Tube No	Designed Steam Temp Degree C	Operating Pressure	Length Of Service (Last light Up Time of Boiler) (hrs)	Zone/ Elevation	Flue Gas Temperature

D — Previous Tube Failure data:

	Tube sample/ Tube No	Location/Elevation	Nominal Dimention of Tube(ODxThk)	Steam Temp Degree C & Pressure	Failure Type	Flue Gas Temperature
1st						
2nd						

E — Boiler DCS Operating Data Study:
Furnace, 1st & 2nd Pass Air & Flue Gas Paths , Steam & Water Ckt Parameters in Cluding SH & RH section
Duration: 1 Months

F — Steam & Water Chemistry Report Analysis:
Duration: 1 Months

G — (01)Failed Tube Sample (Approx 500mm length) & (01) another tube of same location (Send to TCR Advance , Vadodara)
For Hardness, Chemical- Deposit (EDX)Analyis, Metallography Study , Creep Test & PMI Test

H — Purchase Tube IBR Form -IIIB certificate and Received Tubes PMI Report:

I — Boiler Pressure Part Assembly Drawing & ReHeater Assembly Drawings

J — Coal Peroximate Analysis Report : DNA 05.03.2021
Duration: 1 Months

Case Study 1

(Dynamic Creep Rupture of SH tube of 43MW Coal Fired Boiler by Decarburization & Multilayer Oxide Deposit on Both Side)

- History:
- SH Failure Tube Details: SA 213 T11
- Nominal OD X Thk = 55mm x 4mm

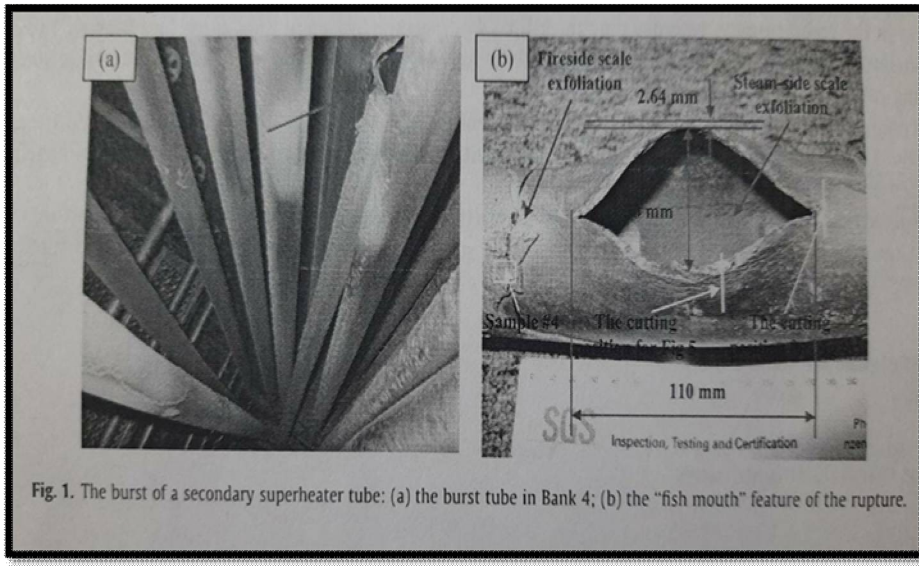
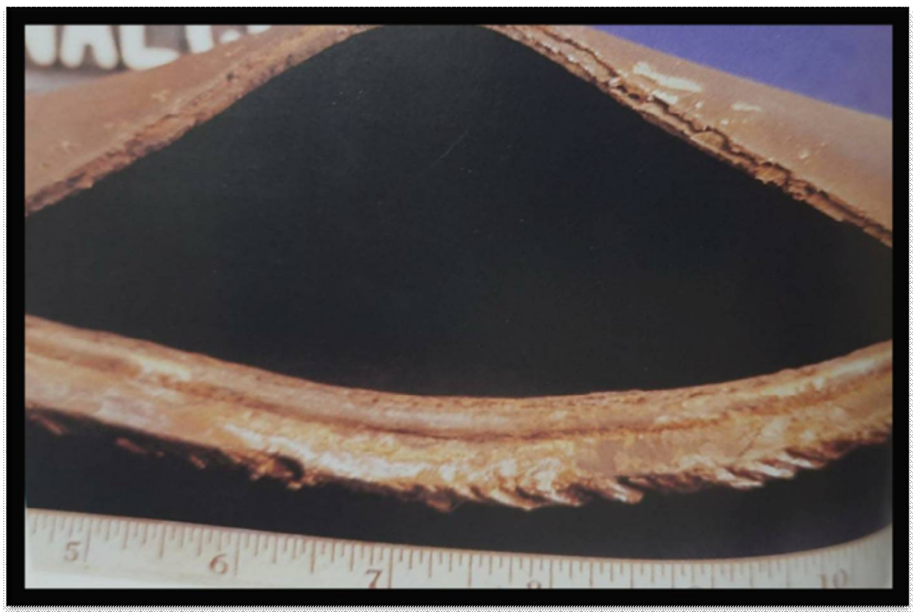
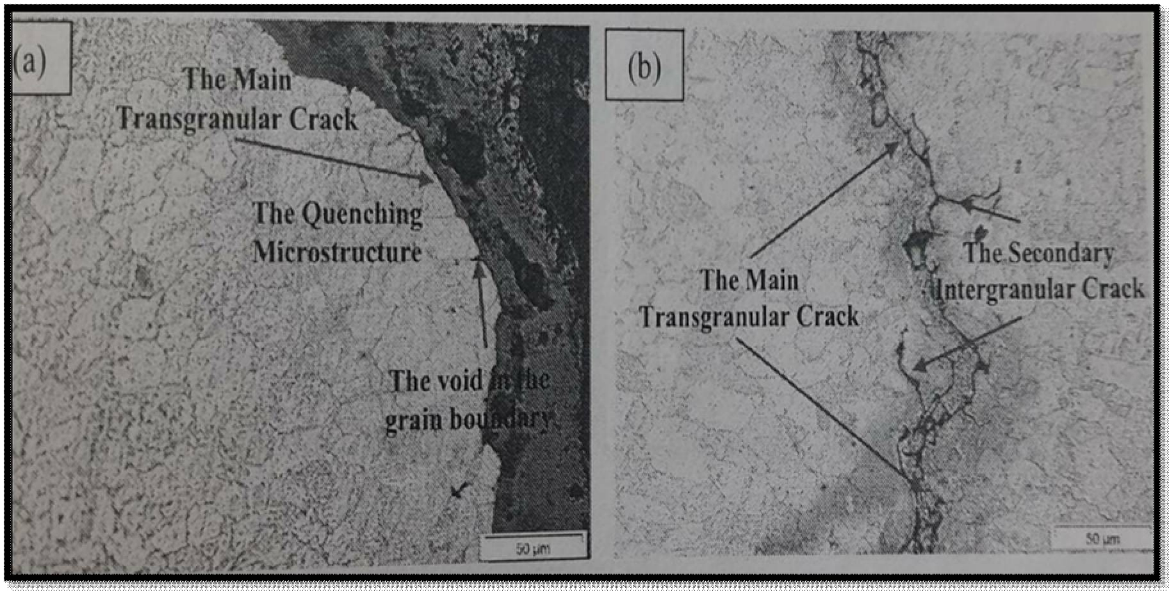


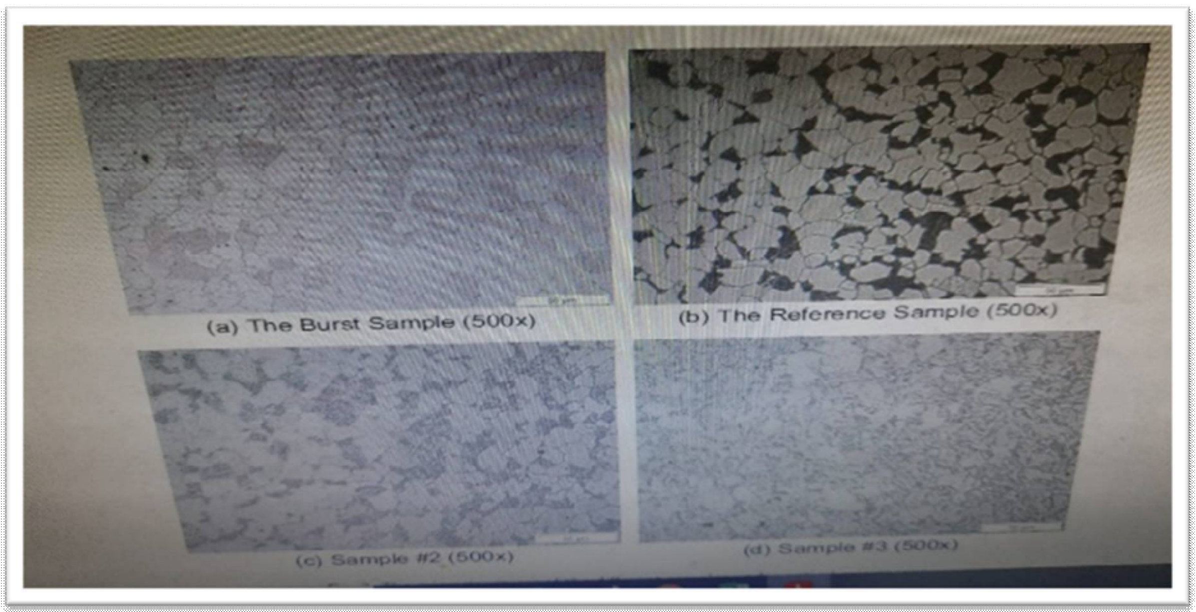
Fig. 1. The burst of a secondary superheater tube: (a) the burst tube in Bank 4; (b) the "fish mouth" feature of the rupture.



Methods of Analysis

- Visual Inspection: fish Mouth Rupture with Thin Lip (Thinned down to 2.64mm)
- Hardness: Hardness result at different positions:
- Hardness (HV5): 186 Burst sample, Refer Sample: 88
- Metallographic Examination:


(a)
The Main
Transgranular Crack
The Quenching
Microstructure
The void in the
grain boundary
50 μm
(b)
The Main
Transgranular Crack
The Secondary
Intergranular Crack
50 μm


(a) The Burst Sample (500x)
(b) The Reference Sample (500x)
(c) Sample #2 (500x)
(d) Sample #3 (500x)

# # # #

FAILURE ANALYSIS OF BOILER, PRESSURE VESSEL, MOTOR DRIVEN PUMP ETC. IN THERMAL POWER PLANT

Team of Wankbori Thermal Power Station
Gujarat State Electricity Corportaion Ltd.

1. INTRODUCTION:

ANALYZING FAILURES is a critical process in determining the physical root causes of problems. The process is complex, draws upon many different technical disciplines, and uses a variety of observation, inspection, and laboratory techniques. One of the key factors in properly performing a failure analysis is keeping an open mind while examining and analyzing the evidence to foster a clear, unbiased perspective of the failure. Collaboration with experts in other disciplines is required in certain circumstances to integrate the analysis of the evidence with a quantitative understanding of the stressors and background information on the design, manufacture, and service history of the failed product or system. Just as failure analysis is a proven discipline for identifying the physical roots of failures, root-cause analysis (RCA) techniques are effective in exploring some of the other contributors to failures, such as the human and latent root causes. Properly performed, failure analysis and RCA are critical steps in the overall problem-solving process and are key ingredients for correcting and preventing failures, achieving higher levels of quality and reliability, and ultimately enhancing customer satisfaction.

It is briefly introduced the concepts of failure analysis, root-cause analysis, and the role of failure analysis as a general engineering tool for enhancing product quality and failure prevention. The discipline of failure analysis has evolved and matured, as it has been employed and formalized as a means for failure prevention. Consistent with the recent trend toward increased accountability and responsibility, its purpose has been extended to include determining which party may be liable for losses, be they loss of production, property damage, injury, or fatality. The discipline has also been used effectively as a teaching tool for new or less experienced engineers.

The importance and value of failure analysis to safety, reliability, performance, and economy are well documented.

For example, the importance of investigating failures is vividly illustrated in the pioneering efforts of the Wright Brothers in developing self-propelled flight. In fact, while Wilbur was traveling in France in 1908, Orville was conducting flight tests for the U.S. Army Signal Corps and was injured when his Wright Flyer crashed. His passenger sustained fatal injuries. Upon receiving word of the mishap, Wilbur immediately ordered the delivery of the failed flyer to France so that he could conduct a thorough investigation. This was decades before the formal discipline called “failure analysis” was introduced.

Conversely, failures can also lead to improvements in engineering practices. The spectacular failures of the Liberty ships during World War II were studied extensively in subsequent decades, and the outcome of these efforts was a significantly more thorough understanding of the phenomenon of fracture, culminating in part with the development of the engineering discipline of fracture mechanics. Through these and other efforts, insights into the cause and prevention of failures continue to evolve.

2. Concepts of Failure Analysis and Prevention

Clearly, through the analysis of failures and the implementation of preventive measures, significant improvements have been realized in the quality of products and systems. This requires not only an understanding of the role of failure analysis, but also an appreciation of quality assurance and user expectations. In an era that initially gained global prominence in the 1980s, corporations, plants, government agencies, and other organizations developed new manage-ment systems and processes aimed at improving quality and customer satisfaction. Some of these systems include Total Quality Management (TQM), Continuous Improvement (CI), and, more recently prominent, Six Sigma. Historically, these initiatives are founded on the philosophies of the quality visionaries W. Edwards Deming (Ref 4) and Joseph Juran (Ref 5).

In their most basic descriptions, TQM and CI represent full organizational commitment to a system focused on "doing the right thing right the first time" and not merely meeting but exceeding customer requirements (Ref 6, 7). They are focused on process improvements, generally in a produ-ction environment. Six Sigma adopts these themes and extends the "reach" of the system to all levels of organizations, with a system to achieve, sustain, and maximize business success. Six Sigma is founded on the use of measurements, facts, and statistics to move organizations in directions that constantly improve and reinvent business processes. The roots of this business system are in the statistical limits set for the maximum number of defects in a product, as a fraction of the total number of opportunities for such defects to occur. To the practitioners of this system, "six sigma" is a statistical metric referring to six times the statistical standard deviation of a normal distribution, which allows no more than 3.4 defects per million opportunities (equivalent to 99.9997% reliability). This is indeed a lofty goal for any organization (be it a manufacturing company, a petro-chemical plant, a service business, or a government agency), but companies committed to Six Sigma have reported significant gains in productivity with simultaneous improvements in organizational culture.

The most positive result of these new management systems is that organizations have responded to the higher expectations of consumers and users and have provided higher-quality products and systems, with attendant increases in customer satisfaction. However, this notion of the quality of a product or system is multifaceted. Juran described quality as "fitness for use". TQM defines quality as the ability to satisfy the needs of a consumer. These characteristics of quality also apply internally to those in organizations, either in the services, or in manufacturing, operating, or administering products, processes, and systems. The intent is to provide not only products and systems that garner high customer satisfaction, but also those increase productivity, reduces costs, and meet delivery requirements.

In general, high quality refers to products and systems manufactured to higher standards, in response to higher expectations of consumers and users. These expectations include such attributes as:

- Greater safety
- Improved reliability
- Higher performance

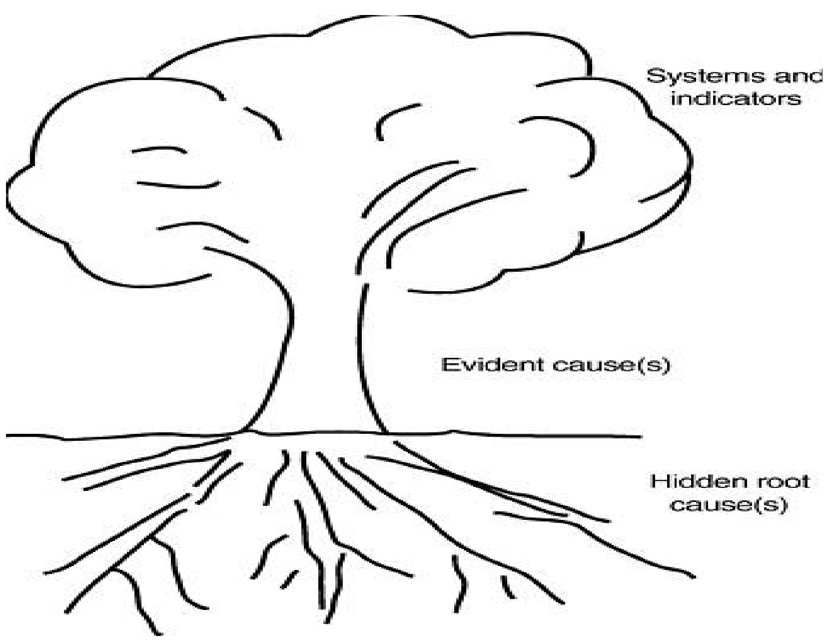
· Greater efficiency
· Easier maintenance
· Lower life-cycle cost
· Reduced impact on the environment

3. Root-Cause Analysis

Failure analysis is considered to be the examination of the characteristics and causes of equipment or component failure.

In most cases this involves the consideration of physical evidence and the use of engineering and scientific principles and analytical tools. Often, the reason why one performs a failure analysis is to characterize the causes of failure with the overall objective to avoid repeat of similar failures. However, analysis of the physical evidence alone may not be adequate to reach this goal. The scope of a failure analysis can, but does not necessarily, lead to a correctable root cause of failure. Many times, a failure analysis incorrectly ends at the identification of the failure mechanism and perhaps causal influences. The principles of root-cause analysis (RCA) may be applied to ensure that the root cause is understood, and appropriate corrective actions may be identified. An RCA exercise may simply be a momentary mental exercise or an extensive logistical charting analysis.

Many volumes have been written on the process and methods of RCA. The concept of RCA does not apply to failures alone but is applied in response to an undesirable event or condition. Root-cause analysis is intended to identify the fundamental cause(s) that if corrected will prevent recurrence



Levels. The three levels of root-cause analysis are physical roots, human roots, and latent roots. Physical roots, or the roots of equipment problems, are where many failure analyses stop. These roots may be what comes out of a laboratory investigation or engineering analysis and are often component-level or materials-level findings.

Human roots (i.e., people issues) involve human factors that caused the failure, an example being an error in human judgment.

Latent roots lead us to the causes of the human error and include roots that are organizational or procedural in nature, as well as environmental or other roots that are outside the realm of control. These levels or root cause are best defined by the two examples in Table 2.

Table 2 Examples of root causes of failure of pressure vessel and bolt

Root type	Pressure vessel failure	Bolt failure
Physical roots	Corrosion damage, wall thinning	Fatigue crack; equipment vibration; lack of vibration; isolation
Human roots	Inadequate inspection performed	Improper equipment installed
Latent roots	Inadequate inspector training	Inadequate specification verification process

How deeply one goes into the root causes depends on the objectives of the RCA. These objectives are typically based on the complexity of the situation and the risk associated with additional failures. In most cases, one desires to identify root causes that are reasonably correctable. An example of the variety of possible root causes of an electric motor driven compressor assembly is provided in Table 3 (Ref 22).

Table 3 Possible causes of electric motor driven pump or compressor failures

System design and specification responsibility	Component manufacturer's responsibility	Shipping and storage responsibility	Installation responsibility	Operations and maintenance responsibility	Distress damage or failed components
Application Under capacity Over capacity Incorrect physical condition assumed (temperature, pressure, etc.) Incorrect physical property assumed (molecular weight etc.)	**Material of construction** Flaw or defect Improper material Improper treatment	**Preparation for shipment** Oil system not clean Inadequate drainage Protective coating not applied Wrong coating used Equipment not cleaned	**Foundations** Settling Improper or insufficient grouting Cracking or separating	**Shock** Thermal Mechanical Improper startup	**Distress damages** Vibration Short/open circuit

Specifications	Design	Protection	Piping	Operating	Failed components
Inadequate lubrication system Insufficient control instrumentation Improper coupling Improper bearing Improper seal Insufficient shutdown devices **Material of construction** Corrosion and/or erosion Rapid wear Fatigue Strength exceeded Galling Wrong hardening method **Design for installation** Unsatisfactory piping support Improper piping flexibility Undersized piping Inadequate foundation	Improper specification Wrong selection Design error Inadequate or wrong lubrication Inadequate liquid drain Critical speed Inadequate strength Inadequate controls and protective devices **Fabrication** Welding error Improper heat treatment Improper hardness Wrong surface finish Imbalance Lube passages not open **Assembly** Improper fit Improper tolerances Parts omitted Parts in wrong Parts/bolts not	Insufficient protection Corrosion by salt Corrosion by rain or humidity Poor packaging Desiccant omitted Contamination with dirt, etc. **Physical damage** Loading damage Transport damage Insufficient support Unloading damage	Misalignment Inadequate cleaning Inadequate support **Assembly** Misalignment Assembly damage Defective material Inadequate bolting Connected wrong Foreign material left in General poor workmanship	Slugs of liquid Process surging Control error Controls deactivated/not installed Operating error **Auxiliaries** Utility failure Insufficient instrumentation Electronic control failure Pneumatic control failure **Lubrication** Dirt in oil Insufficient oil Wrong lubricant Water in oil Oil pump failure Low oil pressure Plugged lines Improper filtration Contaminated oil **Craftsmanship after maintenance** Improper tolerances	Sleeve bearing Seal Coupling Shaft Pinion/ball/ turning gear Casing Rotor Impeller Shroud Piston Diaphragm Wheel Blades; foil, root, shroud Labyrinth Thrust bearing Pivoted pad bearing Roller/ball bearing Cross-head piston Cylinder Crankshaft

Requirements for Effective RCA. Performing an effective RCA requires an interdisciplinary approach in order to ensure that the results are correct and proper corrective actions are identified. In fact, most failures involve factors that spread across many disciplines such as metallurgy, mechanical engineering, hydraulics, electrical engineering, quality control, operations, maintenance, human factors, and others. The analysis team on a complex failure will ideally represent a spectrum of expertise to ensure a very broad perspective.

The best analysis team leader must be a good communicator, have a broad background, be able to integrate factors, and be able to select the best expertise for the project. On less complex failures it is often beneficial to have an individual with a diverse background participate in addition to the specialists, once again to ensure a broader perspective. For example, a metallurgist may be more likely to report a metallurgical deficiency in a product that contributed to the failure, a fabricator is more likely to point to fabrication-related contributors, and a designer is more likely to identify design deficiencies. All of these may be important considerations, but one, all, or none may be a primary root cause. Problems related to people, procedures, environmental concerns, and other issues can also be treated effectively by conducting problem-solving processes and RCAs

4. Case Study-I

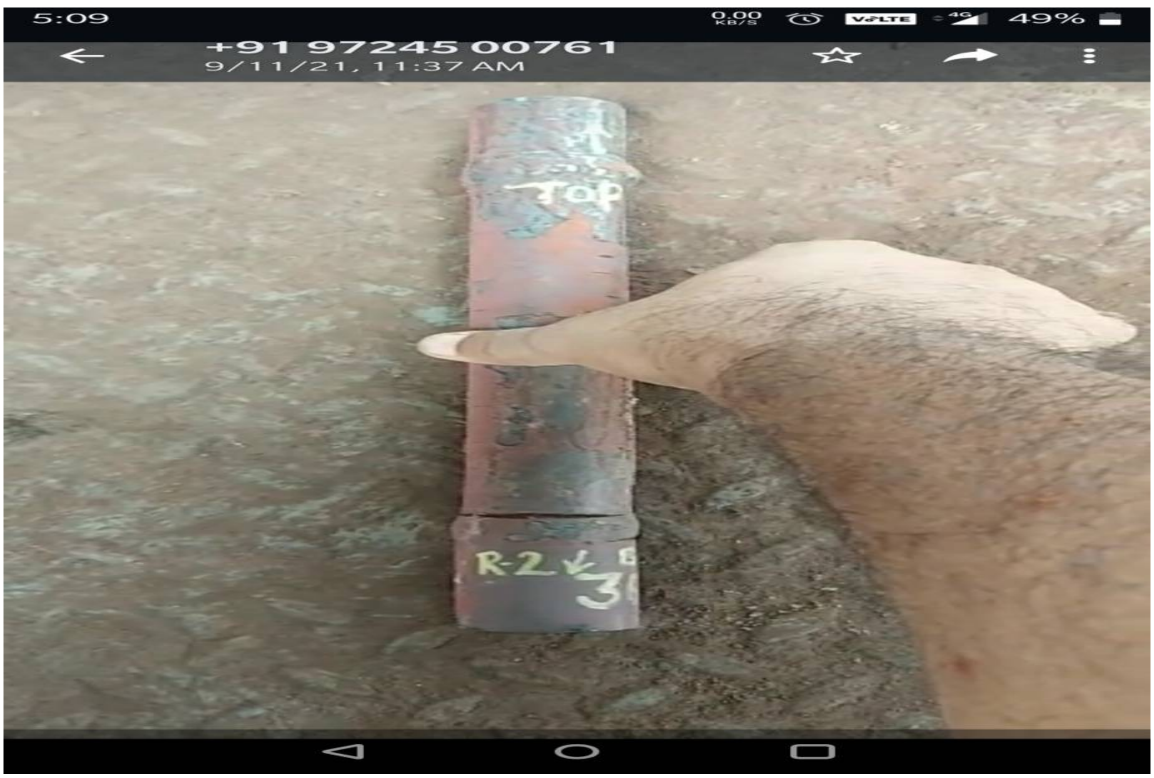
Plant: Bhavnagar Lignite Thermal Power Station

System: Hanger Tube

Failure: Dissimilar Weld Joint Failure (T22 to T91)

Mechanism of Failure: Over Heating

Cause of Failure: Machine Runnig on Low Load for Long Time. Failed tube shows severe overheating especially from T22 (HAZ side). Since low temperature saturated steam is flowing through the back pass hanger tubes, prolonged operation of unit at low load (low steam flow) & high flue gas temperature at back pass inlet could have caused such overheating of tubes. Also frequent start-stop has contributed in failure.



5. Case Study-II

Plant: **Bhavnagar Lignite Thermal Power Station (Circulating Fluidized Bed Combustion)**

System: Comustor

Failure: Comustor Tubes

Mechanism of Failure: Cold End Corrosion

Cause of Failure: Lignite Having High Sulphur Content Deposited On The Surface Of Tube. **Sulphur trioxide and water vapour (moisture) in the flue gas and metal whose surface temp is below the sulphuric acid dew point temp.**

SO_3 - Sulphur in fuel

Moisture – moisture in fuel, tube leakages

6. Case Study-III

Plant: Wanakbori Thermal Power Station

System: Re Heater

Failure: Hot Re-Heater

Mechanism Failure: Fatigue Failure

Cause Of Failure: Welded Clit To Keep Tubes In Alignment Was Restricting Expansion/Contraction

7. Case Study-Iv

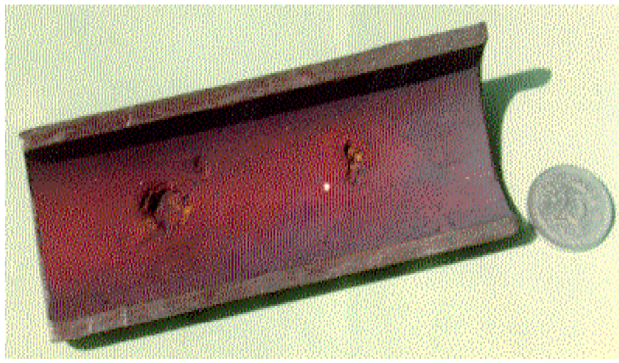
Plant: **Wanakbori Thermal Power Station**

System: **Re Heater**

Failure: Cold Re-Heater

Mechanism of Failure: Oxygen Corrosion

Cause of Failure: Steam Entrapped after Shut Down of Unit converts to Water and with the help Of Oxygen Corrosion initiates.



8. Case Study-V

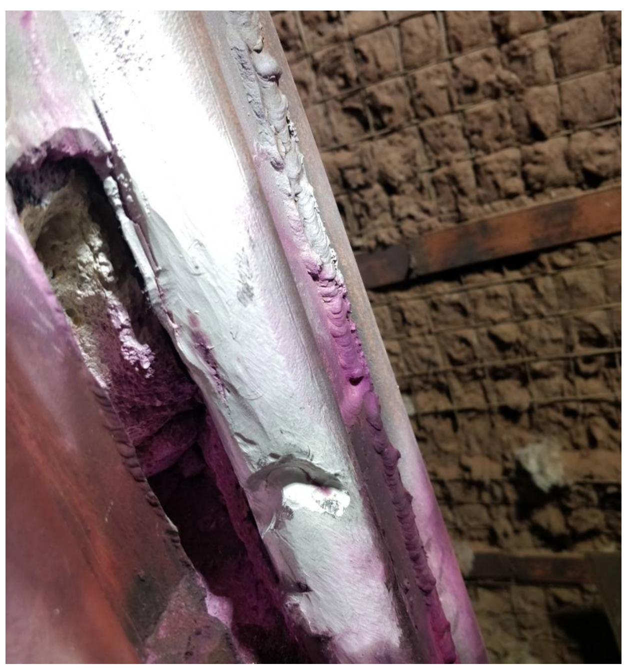
Plant: Bhavnagar Lignite Thermal Power Station (**Circulating Fluidized Bed Combustion**)

System: Convective Path Steam Cool Wall

Failure: Steam Cool Wall

Mechanism of Failure: Fatigue Failure

Cause of failure: Fatigue Failure due to frequent Start -Stop



9. 

CONDITION MONITORING AND NON-DESTRUCTIVE TESTING OF POWER STATION COMPONENTS SUCH AS BOILER, TURBINE ETC.

Team of Wanakbori Thermal Power Station
Gujarat State Electricity Corporation Ltd.

OBJECTIVE

The main objective in presenting this is to share our views, experience and practices followed by GSECL on Condition Monitoring of the Power plant components mainly Boiler and Turbine with the help of Nondestructive testing, Vibration monitoring and analysis, Corrosion test etc.

Methods

The various NDT methods adopted in GSECL for condition monitoring are as follows:

1) Visual examination:

- Visual examination is one of the most powerful means of non-destructive testing, which requires adequate illumination of test surface and proper eyesight of the tester.
- It requires training (Knowledge of product and process, service condition, acceptance criteria, record keeping etc.)

Defects that could be identified by VE

a) Surface defects like erosion; corrosion and pitting, crack, etc. Erosion is generally observed in the Boiler like Economizer tubes, LTSH tubes and Waterwall tubes. Corrosion and pitting are generally observed in waterwall and Economiser tubes. Fatigue Cracks are usually observed in header stub joints whereas stress cracks are generally observed in the attachment welds(fin weld) in water walls and near connectors /spacers given for locking arrangement in Reheater tubes

b) Deposition is mainly observed in the waterwall and platen superheater tubes

c) Discoloration is mainly observed in high heat systems like PSH, FSH and RH as a sign of overheating

d) Misalignment is observed in PSH, RH, FSH etc.

e) Integrity of attachments- It is observed both inside and outside the Boiler

f) Clamp position- In PSH, FSH, RH

g) Sleeves and cassette position- Observed in Eco, LTSH, screen tubes etc.

Figure 1 Bulging found in rear arch sleeves and tubes

Figure 2 Corrosion in secondary coal crusher

Figure 3 Mechanical rubbing observed in PSH tubes with spacer tubes

2) **Ultrasonic testing:** Technique used for subsurface defect detection which uses high frequency sound waves, typically above 2MHz to pass through a material. Probe is used which transmits and receives ultrasonic pulses and gives digital display. By using this technique extensive tube thickness survey is carried out on the pressure part components by means of Digital thickness meter in order to gauge the reduction in metal thickness.

   Internal oxide measurement in PSH-RH-FSH to monitor the overheating of tubes. It is also used to monitor the condition of Turbine bearings, bonding of Babbit metal of turbine bearings and other journal bearings and pads, shafts of CW pump system etc.

3) **Magnetic particle inspection:** This technique is used to detect surface and subsurface cracks mainly in header stub joints as well as gamma plug joints of headers of various pressure part systems.

4) **Dye Penetrant Testing:** This technique is used to detect surface fatigue cracks mainly in PSH dissimilar weld joints, stub joints of various headers, turbine bearings, turbine thrust pads, shafts of CW system, boiler drum attachment welds, etc.

Figure 4 DP testing of FSH Stub joints

Figure 5 DP testing of PSH DMW joints

Figure 6 DP testing of drum internals

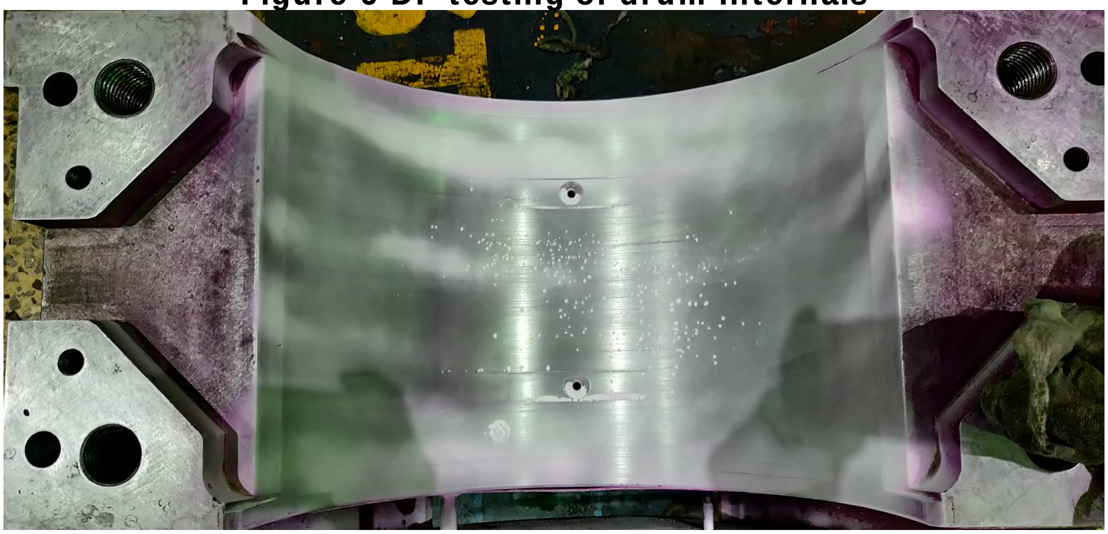


Figure 7 DP testing of turbine bearing

5) **Radiography Testing:** This technique is used to detect surface and subsurface defects in boiler tube weld joints by imposing X or Gamma radiation upon the test object. Pitting in CRH bends is also checked by this technique by GSECL. The radiation is transmitted to varying degrees dependent upon the density of the material through which it is travelling. The major advantages of RT testing include permanent record, very little requirement of surface preparation, flexibility of usage across most materials. Of late, looking to disadvantages of RT such as radiation hazard possibility, need to vacate area while RT is being carried out etc., metallurgy section at WTPS, GSECL has started a gradual transition from RT to PAUT testing.

6) **Phase Array Ultrasonic Testing (PAUT):** This technique is used to detect surface and subsurface defects in boiler tube weld joints as well as pipe joints. PAUT is an advanced UT method whose main feature is the computer-controlled excitation (amplitude and delay) of individual elements in a multi element probe. PAUT gives defects with dimension, and it can be carried out without stopping other parallel activities. PAUT is also operator friendly as it doesn't involve any radiation usage. The

main reason PAUT cannot totally displace RT is that PAUT isn't feasible for components below 4 mm thickness.

In addition to the above NDT methods, vibration monitoring of various pumps and motors, fans, pulverizers, etc.; and corrosion testing of structural components also are important techniques which contribute a lot towards condition monitoring of power plant components which have been adopted by GSECL.

7) **Corrosion testing**: The main purpose of carrying out corrosion testing is to measure the following.
   - Material loss
   - Unintended fixing
   - Member distortion
   - Component destruction
   - Design capacity Vs present structure capacity

Looking to the above points, it is inferred that condition monitoring is very much essential in order to ensure the stability and healthiness of the power plant and NDT is one of the major tools to ensure the above. Moreover, it also emphasizes the importance of the role of a metallurgist in power sector, especially in the present scenario where more and more supercritical power plants of higher capacities (660/800MW) are coming up in place of lower capacity plants (120/210).

DEVELOPMENTS & UP GRADATION IN MATERIALS FOR RELIABLE AND EFFICIENT TRANSFORMER

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ABSTRACT:

Development is going on from when the 1st single phase transformer developed by Mr. Stenly in 1886.Power flow within networks is becoming increasingly complex. There is a higher probability of unforeseen peak demands throughout the day, which create major energy challenges of today and tomorrow: Like energy efficiency, market efficiency, grid reliability, space concern and environmental concerns. Hence utility demands for sustainable range of green eco-efficient power transformers, Ester oil based transformers are looking more reliable for all above aspect compare to mineral oil and the addition of TUP and CTC will greatly enhance the loading capability of power transformer. Also RIP Bushing and HDG Paint will play a major role for more efficient transformer as per today's scenario.

1. Mineral Oil

Need of higher fire point, environment friendly, and fire safety new fluids become alternative to mineral oil. Worldwide global emission of CO2 jumped causing a global temperature increase of 3.5°C. So, mineral oil **replaced by**

Ester Oil:

Increased load ability, lower CO_2 emissions, limitation of environmental risk, noise reduction, space savings, because of high fire point. (360°C)

2. Paper Insulated Copper Covering (PICC):

This is the principal type of conductor used for winding of transformer. Type of insulation paper such as Kraft paper. Due to lower short circuit strength in higher current rating transformer causing **PICC replaced by**

Thermally Upgraded Paper: which is suitable for Hot-spot temperature of about 110°C.It is possible to meet the special overloading condition.

Enamelled Rectangular Copper Conductor:

This is coated by the various enamel films on the bare. **CTC conductor** best option for reducing stray flux, eddy current losses and improves the thermal performance.

Nomex Paper Covering:

For better mechanical properties Nomex paper can be used as an interlayer insulation for a multilayer winding.

3. OIP Bushing:

OIP Bushings are contain Porcelain provided with Oil level gauge & Test Tap;But due to certain drawbacks now it is gradually **replace by**

RIP Bushing:

Which is much better in terms of handling, tan delta & durability against conventional OIP Bushing.

4. PU Paint:

Paints are generally not resistant to scratching, cracking, or impact, resulting in a compromised coating so, due to above uncertainties PU paint **replace by**

HDG Paint:

For atmospheric condition & reduce leakage HDG paint is one of the best options.

In this Paper we will discuss all above points in detail which finally support to the up gradation of transformers.

MINERAL OIL

What is Mineral Oil?

Petroleum based purified mineral oil has been used in transformer for over hundred years.

For most transformers mineral oil is the most efficient medium for absorbing heat from the core and the windings and transmitting it, sometimes aided by forced circulation, to the naturally or artificially cooled outer surfaces of the transformer. The heat capacity, or specific heat, and the thermal conductivity of the oil have an important influence on the rate of heat transfer

What is negative effect on Environment & Transformer due to Mineral Oil?

- The major limitations of mineral oil are low biodegradation and panic threats to human beings and eco system.
- Due to their poor performance at high temperature, the use of mineral oil is restricted in ecologically sensitive locations.
- Mineral-oil-filled transformer explosions and fires causing heavy collateral damage have raised major safety concerns.
- There has also been major environmental concern over the toxic effects of uncontained mineral oil spills.
- Above all, petroleum products are eventually going to run out and there could be serious shortages even by the mid-twenty-first century.

This has given rise to a new class of alternate natural sources of dielectric insulating fluids

ESTER OIL

Ester oils are dielectric coolants designed for use in distribution and power class transformers. They may be natural or synthetic in origin, deriving from commodity seed oils or inorganic feed stocks. While the specific formulations are proprietary, these dielectric fluids are biodegradable compounds combined with a small percentage of biodegradable additives for performance enhancement.

Increased fire safety and energy efficiency of power transformers using natural ester deeply affects the criteria for transformer selection among electric utilities and grid companies. Natural ester made up of renewable source helps achieve greater continuous load capacity to better handle demand fluctuations Current loading profiles based on mineral oil transformer limits may not be able to withstand those inconsistent demands.

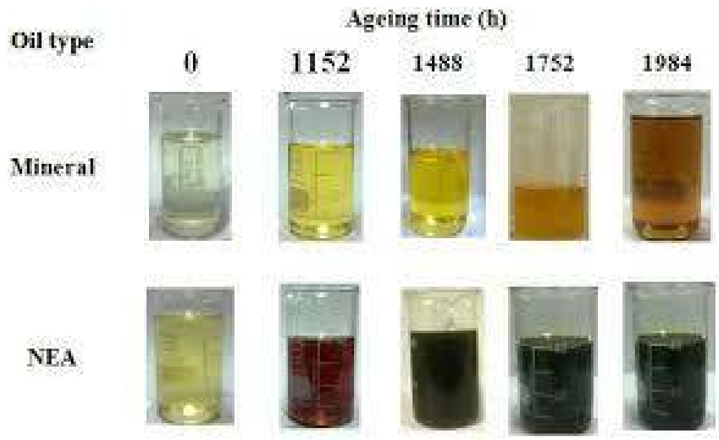
Advantages:

- Environmentally friendly
- Nontoxic and readily biodegradable
- Non-hazardous to water
- The by-products of natural esters after combustion are also much less toxic than the ones of mineral oils,

which further minimizes their overall impact on the environment.

- have a flash and fire point above 300°C
- Because of the natural esters' greater water saturation limit, less moisture is held into the cellulose insulation materials
- Low degradation rate of insulation paper
- Low pour point

Ageing time comparison of insulation paper in Mineral oil and Ester Oil



Actual site image of Atlanta make Synthetic Ester oil filled transformer

Actual site image of Atlanta make Natural Ester oil filled transformer

	COMPARISION: ESTER OIL v/s MINERAL OIL		
Sr. No.	**Characteristic**	**Mineral oil**	**Ester oil**
1	Density	0.89 Gm/cm^3 at 29.5 ^0C	Max.1.0 Gm/cm^3 at20 ^0C
2	Kinematics viscosity	27 cst at 27 ^0C (Max)	Max.15 mm^2/s at 100 ^0C Max.50 mm^2/s at 40 ^0C
3	Flash point (Min)	140 ^0C	250 ^0C
4	Pour point (Max)	(-6) ^0C	(-10) ^0C
5	Fire point(Min)	170 ^0C	300 ^0C
6	Calorific value	high	low
7	Corrosive sulphur (in Terms of classification of copper strip)	Noncorrosive	Noncorrosive
9	Electric strength (breakdown voltage) (Min) (A) New unfiltered oil (B) After filtration	 30 kVrms /minute 60 kVrms /minute	 Min.35 kVrms /minute Min.70 kVrms /minute
10.	Die electric dissipation factor (tan delta) at 90 ^0C (Max)	0.002	0.05
11	Water content (Max) by weight - Untreated new oil - After treatment	 50 ppm 15 ppm	 100 ppm 50 ppm
12	Biodegradation	Poor biodegradability	Good biodegradability
13	Safety	low	high
14	Fossil/non fossil	fossil	recyclable
15	Effect on environment	Worse effect	Environment friendly
16	Ageing/degradation rate of insulation	fast	slow

COPPER CONDUCTOR INSULATION PAPER

Important Electrical properties for paper insulation

1) High dielectric strength
2) Dielectric constant in oil-filled transformers as close as possible a match that of oil
3) Low power factor (dielectric loss)
4) Freedom from conducting particles.

KRAFT PAPER

- Paper is among the cheapest and best electrical insulation material known.
- Kraft paper is, by definition, made entirely from with paper Insulation unbleached softwood pulp manufactured by the sulphate process
- They were not desirable in high-stressed areas such as angles and corners (boundary areas) as the voltage rating increased.
- Has a thermal class rating of only 105°C,
- Thermal resistance for heat transfer from paper to oil is low

TUP

- Better temperature stability
- Reduced thermal degradation
- The superiority of the upgraded papers was demonstrated by both short-term and long-term aging.
- Increase the insulation life
- Transformers rated at 55°C oil rise could be upgraded to 65°C oil rise, which meant the insulation life was extended by at least three times
- Thermal class could reach up to 120°C
- For TUK paper the uprising intervals are 60~80℃
- Moreover, the aging of winding insulating material will be slowed down comparatively.

NOMEX COVERING

- This material can be made into a range of papers and boards in a similar way to cellulose fibres but which remain stable at operating temperatures of up to 220°C.
- In addition, although the material will absorb some moisture dependent upon the relative humidity of its environment, moisture does not detract from its dielectric strength to anything like the extent as is the case with cellulose-based insulation
- Has a considerably higher thermal rating (220°C).
- Low moisture absorption
- Higher cost

CTC

- The individual conductor is insulated with super enamel covering & all conductors are finally insulated together with paper insulation
- The odd conductor in two stacks are continuously transposed at regular interval so that eddy current losses are minimized.
- The introduction of continuously transposed strip has been particularly beneficial to the design of large transformers, which must be capable of carrying large currents
- Enables a far greater number of transpositions to be carried out.
- Net improvement in space factor as well as improved uniformity of ampere-conductor distribution.
- The strand insulation can be over-coated with bondable epoxy. These epoxy resins cure under the same thermal conditions applied to the cellulose components in the drying process of the winding.
- Epoxy bonded transposed cable are characterised by very high mechanical strength, which enables the winding to withstand high electro-dynamic forces, e.g. in the event of short circuit.
- Enamelled covered conductor are used nowadays in power transformers winding due to high capitalization of load loss.
- CTC conductor is best option for reducing stray flux, eddy current losses and improves the thermal performance (decrease in tempe-

rature gradient by over 50%), increase space factor up to 30%.

- **OIP Bushing**

In OIP bushing the core is wound from paper and subsequently treated and impregnated with an insulating liquid, generally transformer oil. The core is contained in an insulating envelope (generally "Porcelain"), the space between the core and the insulating envelope being filled with the same insulating liquid as that used for impregnation. In the centre stem is provided which connects the Overhead conductor to transformer winding, this is usually made of copper. The traditional OIP bushing technology uses oil as its basic insulating medium. Use of oil has many severe drawbacks in bushing life, such as being susceptible to moisture ingress and oil leakage due to worn out seals. In turn greater vulnerability in an OIP bushing exists to lightning strikes or other factors that can trigger explosive failure. Additionally, excessive filling of oil reservoirs in horizontal mount applications can lead to severe operational problems. Unusually high operating temperatures on an OIP bushing can comprise its bushing life and again lead to severe operational problems.

Power Transformers failure rate are 14% due to OIP bushings. Following are the major causes of OIP bushing failures:-

i. Oil leakage
ii. Test Tap unearth
iii. Irregular maintenance
iv. High Electrical Stress
v. Crack in the Porcelain
vi. Improper Installation/handling
vii. Insulation deterioration (high PD /Tan Delta)
viii. Manufacturing /Material defect

- **RIP Bushing**

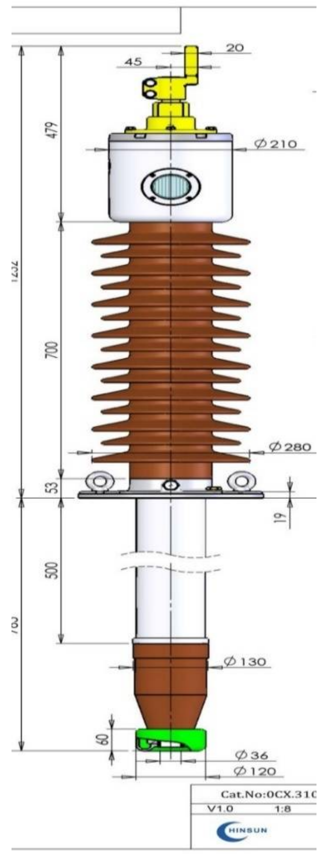
In RIP bushing the major insulation consists of a core wound from paper and subsequently impregnated with epoxy resin. The casting and curing of this insulation is a carefully controlled process.

A resin-impregnated paper bushing can be provided with an insulating envelope (generally "Silicone Composite insulator"), in which case the intervening space can be filled with an insulating liquid or another insulating medium like polyurethane foam, gel etc.

COMPARISION: OIP BUSHING v/s RIP BUSHING		
	OIP Bushing	**RIP Bushing**
PD level	5 pC,	2 pC,
Tan Delta	0.45 % or lower	0.35% or lower
Insulation Class	Class-A (up to 105^0C).	Class-E (up to 120^0C)
Weight	more	Less
Maintenance	more	Less
Seismic Withstand capability & Mechanical Strength:	low	High

Capacitance	Low	High
Installation/commissioning	Time consuming	Easy
Flammability & Explosion Risk:	high	Non-flammable/ Non-explosive
Cost Aspect	Less than RIP	Costly
Handling/ Transportation	Not easy	Easy

Transformer with OIP Bushing



Transformer with RIP Bushing

➢ PU PAINT RADIATOR

- There are significant material and labor costs associated with packaging painted structural steel or steel assemblies for shipping, including wooden age and soft material (paper, cardboard) interleave to prevent contact between individual pieces
- There is usually a time-consuming inspection and field touch-up necessary to repair damaged areas of painted bare steel.
- Whether the application of paint is done in the factory or field, the internal tubular sections and hard to reach areas of bare steel remain unprotected; these areas are where corrosion usually begins.
- Painted systems often experience project delays because of unpredictable weather. When the parameters of safe and quality painting (temperature, humidity, wind) are stretched or compromised, coating failure is almost assured
- Paint is a barrier protector only, and when scratches and cracks occur, corrosion of the underlying steel is immediate.
- Paint coating thickness on all surfaces is a variable and uniform as the applicator, with corners and edges highly susceptible to corrosion because of thin films
- Paints are generally not resistant to scratching, cracking, or impact, resulting in a begins and maintenance painting is required.
- Sun, heat, wind and weathering are constants that result in paint typically requiring touch-up and replacement in 12-15 years, costing far more than galvanizing over the intended life of the project
- Paint is a barrier protector only, and when scratches and cracks occur, corrosion of the underlying steel is immediate
- Paint coating thickness on all surfaces is a variable and uniform as the applicator, with corners and edges highly susceptible to corrosion because of thin films
- Paints are generally not resistant to compromised coating where corrosion begins and maintenance painting is required.
- scratching, cracking, or impact, resulting in a compromised coating where corrosion begins and maintenance painting is required

➢ HDG RADIATOR

- The zinc-iron alloy layers of the hot-dip galvanizing (HDG) steel coating are harder than steel and are unaffected by rough handling typical during shipment and erection. Bending of HDG steel pieces in contact with each other is common and acceptable.
- Field touch up rarely needed for HDG steel unless for cosmetic reasons to hide a chain mark or to provide corrosion protection to a field-modified area
- Galvanizing is always factory-controlled, with a precise, scientific methodology that ensures complete coverage and corrosion protection.
- Hot-dip galvanizing can be done 24/7/365, the process is totally independent of weather conditions

- Hot-dip galvanizing provides both cathodic and barrier protection to steel, delivering a rust and-maintenance-free system in most environments for 75 years or more
- The metallurgical reaction between 840F molten zinc and iron in steel ensure a uniform and guaranteed coating thickness, documented in ASTM specifications
- The alloying of zinc and iron in the HDG coating means the zinc and steel metallurgically become one, yielding a coating bond ten times greater than the strictly mechanical bond of paint to steel
- With a coating hardness greater than the steel alone, galvanized steel provides a durable, scratch-resistant coating that maintains the integrity of overall corrosion protection system Hot-Dip Galvanized steel commonly provides maintenance-free corrosion protection for 75 years or more in atmospheric use, especially as our environment and air have become cleaner as a result of regulation.
- Hot-Dip Galvanized steel commonly provides maintena-nce-free corrosion protection for 75 years or more in atmospheric use, especially as our environment and air have become cleaner as a result of regulation.

COMPARISON: HDG PAINT RADIATOR V/S PU PAINT RADIATOR		
	PU Paint Radiator	**HDG Radiator**
Special Handling	required	Not required
Field Touch-Up	required	Not required
Weather Dependent	Yes	No
Temperature Range	< 200^0F_	-75^0F to 392^0F
Coating Thickness	variable	> 3.9 Mils
Corrosion Protection	Barrier	Cathodic & Barrier
Bond Strength	600 psi	3600 psi
Hardness/Abrasion Resistance	Varies by Type	179 to 250 DPN
Service Life - Atmospheric	12-15 Years	75 Years

CONCLUSION

- In this paper we explained all replaced material in last two decades with specification & properties.
- For green transformer & fire safety, ester base oil is preferred
- For reducing stray loss, production time, increase age of transformer by using enamelled conductor, CTC, Nomex covering
- For reducing transformer failure because of bushing basically OIP, we introduce RIP bushing
- For atmospheric condition & reduce leakage HDG paint is one of the best option

COPPER IN POWER

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ABSTRACT:

Copper is a base metal that is used in thousands of copper products to build components, equipment, etc., such as motors, generators, reactors, transformers cables wires etc., that are used in power systems such as technical installations in buildings, electricity grids or renewable power plants. This paper presents history and usages of copper over the years.

HISTORY OF COPPER:

Copper was the first metal used in quantity by humans. Since 10,000 BC, copper helped to pull mankind out of the Stone Age. The story of copper and its principal alloys, bronze, and brass is virtually a chronicle of human endeavor. Initially, native copper was used to exploit copper's corrosion resistance, good workability, and high thermal conductivity. Around six millennia ago, humans mastered the skill to extract copper from ore and went on to alloy copper into bronze for improved strength and durability. The copper was first used for electrical sector nearby year 1837 as a cable.

COPPER RESOURCES:

Largest copper producing countries in the world by 2020 mining production (May 2021)

- Chile – 5.7 million tonnes.
- Peru – 2.2 million tonnes.
- China – 1.7 million tonnes.
- Democratic Republic of Congo – 1.3 million tonnes. .
- United States – 1.2 million tonnes.

2020

Rank	Country/region	Production (thousand tons of)[1]
	World	16,890
1	Chile	5,700
2	Peru	2,200
3	China	1,700
4	Congo, Democratic Republic of the	1,300
5	United States	1,200
6	Australia	870
7	Russia	850
8	Zambia	830
9	Mexico	690
10	Kazakhstan	580
11	Canada	570
12	Poland	400

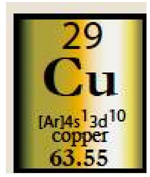
Copper production in India is about 340 thousand tons which is about 2 percent of world copper production. Largest reserves/ resources of copper ore to a tune of 181 thousand tons (53%) are in the state of Rajasthan followed by Jharkhand with 64 million tons (19%) and Madhya Pradesh with 63 tons (18%).

PROPERTIES OF COPPER:

Copper is a chemical element that is soft, malleable, and ductile. Copper has very high thermal and electrical conductivity. Copper's symbol is **Cu** and its atomic number is **29**. Copper melts at about 1,984°F (1,085°C).

1) **Physical Properties:**

Atomic structure



- Atomic number 29
- atomic weight 63.55,
- periodic table group 1B above Ag and Au,
- 29 protons, 34-36 neutrons, 29 electrons.

***Density*:**

- 8.9 g/cm^3 = kg/dm^3 = t/M^3 (values reported from 8.90 ... 8.95, depending on oxygen content). *[Al: 2.7, Fe: 7.9, Ag: 10.5]*

***Coefficient of thermal expansion*:**

- 17 µm/(M x ℃) (for a kM cable, 17mm/℃). *[Al: 23]*

***Typical impurities* in ETP copper:**

- 400 ppm = 0.04% (of which 200 ppm oxygen), hence copper is 99.96% pure.

2) **Electrical Properties:** *IACS* (International Annealed Conductivity Standard):

- A wire of 1 M long, weighing 1 g, having a density of 8.89 g/cm^3, measured at 20℃, exhibits a resistance of 0.15328Ω. This value was assigned a volume conductivity of 100% IACS. It corresponds to a volume resistivity of 0.017241 (Ω x mm^2)/M = 1.7241e-6Ω x cm. [Al 2.82]
- *IACS %* = 172.41/resistivity with the resistivity value expressed in (µΩ x cm). [Ag 106% Au 70% Al 61%, Fe 17%, Pb 8%, stainless steel 2%]
- *Volume conductivity* for 100% IACS: 58 MS/m (1/58 = 0.017241)
- ***Mass resistivity***: 153 (µΩ x kg)/m2. Note: mass resistivity = volume resistivity x density. [Al 76.14]
- ***Temperature variation of resistivity*:** 68e-6 (Ω x mm^2)/(M x ℃) at 20℃
  - ➤ **Resistivity at 0℃:** 0.017241 - 20 x 68e-6 = 0.01588 (Ω x mm^2)/M (109% IACS)
  - ➤ **Resistivity at 70℃:** 0.017241 + 50 x 68e-6 = 0.02064 (Ω x mm^2)/M (84% IACS)

3) **Thermal Properties:**

***Thermal conductivity*:**

- 398 W/m x K at 20℃, 574 at -200, 381 at +200. [Al: 230]
- ***Specific heat*:** 385 J/(kg x ℃). [Al: 900]
- ***Melting point*:** 1083℃. [Al: 660]
- ***Latent heat of fusion*:** 205 J/g. [Al 395]

4) **Mechanical Properties:**

***Tensile strength*:**

- as cast 150-170 N/mm^2, annealed 200 - 250, half-hard: 260 - 300. [Al annealed 50-60, half-hard 85-100]
- ***Elastic modulus*** *at 20℃*: annealed 118kN/mm^2, cold worked 118 - 132. [Al 65]
- ***Fatigue resistance*** (50e6 cycles): annealed 62 N/mm^2, half-hard 115 N/mm^2. [Al respectively 20 and 45]
- ***Creep*** (minimum rate, %/1000 h, 150℃, 26 N/mm2 stress): 0.022. [Al: same creep rate for similar stress at 20℃]
- ***Hardness*:** 400-900 N/mm^2. 45-130 HV. [Al 180-400]

5) **Electrochemical Properties:**

Electrochemical equivalent:

- Cu^{++} 0.329 mg/C, Cu^{+} 0.659 mg/C.

- ***Electrode potential*****:** Cu++ -0.344 V, Cu+ -0.470 V.

6) Alloying Properties:

- ***Strength*****:** Al, Mn, Ni, Si, Sn, Zn, Zr
- *Corrosion resistance*: Al, As, Mn, Ni, Si, Zn
- *Strength* & high conducti-vity: Be, Cr, Fe, Ni+Si_Cr, Ti
- *Wear resistance*: Al, Ag, Cd, Si, Sn
- *Machinability*: Pb, S, Zn
- *Heat resistance*: Cr, Mg, Zr

USES OF COPPER:

Copper is used in 13 important applications such as Aircondi-tioning, Aquaculture, Architecture, Art, Coinage, Design & Manufa-cturing, Electrical systems, home appliances, Energy & Renewables, Farming & Agriculture, Marine, Pipe Systems, Transport etc.

Copper is among the best conductors of electricity and heat. Use of copper in power system is in generation, transmission & distribution, electronic product, relays, copper wiring and radiators are integral to the appliances, heating and cooling systems, and telecommunications links used every day in homes and businesses. Copper is an essential component in the transformers, reactors, chokes, solenoids, motors, wiring, terminal cone-ctors, etc.

Copper is a material that flows into products (e.g., conductors, wires, cables, bus-bars, tubes, etc.) that are used in components to build the systems, appliances, equip-ment that produce benefits for end-users.

COPPER USES IN POWER SECTOR:

Within power sector also there are numerous applications wherein the use of copper is necessary. Few are discussed herein.

1) Electricity and Energy:

Weight for weight, outside precious metals, copper is the best conductor of electricity and heat. Copper is used in high, medium, and low voltage power networks, and copper conductivity is considered to be the standard by which other conductors are measured.

The unique combination of strength, ductility and resistance to creep and corrosion establishes this non-ferrous metal as the preferred and safest conductor for wiring in buildings. An essential component of energy-efficient motors and transformers.

2) Wire and Cables:

Copper's conductivity is almost twice that of aluminum, which makes copper the material of choice for high energy efficiency applications.

Having high conductivity combined with ductility makes it easy to draw down to close-tolerance diameters, it can also be readily soldered, crimped to make economic, durable connections. It is compatible with all modern insulation materials, but its good oxidation resistance means that it can also be used without any surface protection.

One of the major copper user is railways. All the electrified tracks are strung copper wires only. The pantographs current carrying parts are of copper only.

3) Busbars:

Because of its good conductivity

strength, connectivity, ductility and resistance to oxidation, copper is the most obvious material to specify for the manufacture of bus-bars. High conductivity copper billets are hot extruded into a regular cross section, followed by drawing down to the necessary finished size.

1) Generator, Transformer and Motor Windings:

Copper used for the manufacture of transformer windings is in the form of wire for small ratings and strip for larger ratings. For which, the copper wire provides strength to wound without breakage, yet flexible enough to give close-packed windings. Strip has good surface quality so that insulating enamels do not break down under voltage. Copper provides better ductility, which is essential for the strip to be formed and packed, and good strength needed to withstand the high electro-mechanical stresses set up under severe short-circuit conditions.

The properties needed for motor windings are like those needed for transformers, but with the additional requirement to with-stand mechanical vibration and centrifugal forces at working temperatures.

2) Electrical Sub stations:

Copper is used in electrical equipment like circuit breakers, CTs, PTs, bushings, capillaries, contactors, dis-connectors, terminals etc., in the form of components and accessories. Copper is also being used in the form of strips for all sort of earthing, risers, grid earth mesh, electrode grounding etc. It is also used for lightning protection in the form of spikes.

3) Electronic Equipment:

Copper plays a vital role in several small, high-tech applications. Copper or copper-base alloys are used in relay contacts, terminals, Printed Circuit Boards, in electronic connectors and lead-frames. In addition, it has long been used in telecommunications, and is now increasingly used in IT, notably for the manufacture of microchips and in semi-conductor applications. Copper heat sinks allow dispersion of heat from high-frequency microprocessor and logic devices.

4) Other Electrical Engineering Uses:

Copper is also used for manufacturing commutators, welding electrodes, contacts, contact springs, high vacuum, and other electronic devices.

5) Renewables:

Because copper is a highly efficient conductor of electricity and heat, it is used in renewable energy systems to generate power from solar, hydro, thermal, tidal, biomass, geothermal and wind energy across the world. Copper helps reduce CO_2 emissions and lowers the amount of energy needed to produce electricity. In many renewable energy systems, there is 12-times more copper being used than in traditional systems to ensure efficiency. Copper is one of the best renewable resources. It is one of the few materials that can be recycled 100 percent over and over again without a loss in performance. Renewable energy sources provide nearly one-quarter of the world's power, and copper plays an important role in making it as efficient as possible with minimal impact on the environment.

6) Solar Heating:

Copper's combination of high heat conductivity, resistance to atmospheric and aqueous corrosion, ease of fabrication, sealability (joining by soldering), mechanical strength and longevity offer strong advantages over any other material in solar heating applications.

7) Wind Energy:

The primary use of copper in wind energy technologies is in the form of coil windings in the stator and rotor portions of the generator, in the high-voltage power cable conductors, transformer coils and earthing.

8) Photovoltaics:

Copper forms part of the materials presently used for photovoltaic solar cells, module cables, panel wiring, string controller, junctions box feeding cables, earthing, inverter, transformers, and photovoltaic cell ribbons.

9) New applications:

In addition, the obvious trend towards distributed generation and a decentralized system relies on more storage and increasing demand side flexibility solutions, which often rely on copper-based technologies.

A low-carbon future is not possible without smart end connected electrical and thermal grids. Copper is a key metal to making these grids smaller, smarter, more flexible and more energy-efficient.

Beyond the energy sector, copper is a key component in new, low-carbon modes of transportation, such as for electric vehicles, playing an important role in their batteries and control systems as well as the charging infrastructure. Electric vehicles are 2-3 times more copper intensive than combustion cars.

Building automation and control systems (BACS) controlling building's mechanical, electrical, plumbing, lighting, HVAC and security systems as well as its elevators and escalators more efficiently and so reduces the building's energy consumption and environmental footprint. They do this through an array of sensors and controllers via a user interface or dashboard.

Use of Copper By product:

Overall, 60% of copper use in the form of wire & cable products. Roughly a quarter of extruded and rolled products are used for electrical conductivity applica-tions, bringing the total for conductivity to 70%. Non-alloyed copper products represent 80% of use with the remaining 20% of copper use spread over 400+ alloys.

Use of Copper by Market:

The building construction market represents almost 30% of end-use. This segment covers fixed technical installations in buildings (data, electrical, heating, water). Among these, electrical installations are the most important application.

Power, telecom and transport networks represent close to 20%. Power infrastructure dominates.

Around 45% of copper is used in manufactured goods - consumer, HVAC, industrial, office and transport equipment.

Finally, 10% covers 'the battalion of everything else', copper in coins, ammunition, clothing, toys, etc.

COPPER BENEFITS by Property:

1) Conductivity: Copper and aluminum are both extensively used as electrical conductors. Aluminum has about 60% of copper's conductivity, or copper is about 66% more conductive for electricity. Aluminum is 3.3 times lighter than copper. Hence, for the same current carrying capacity and for same efficiency (in ohmic regime) the copper conductor required will be 3.3/1.66 = 2 times heavier. An equivalent aluminum conductor will be 1.66 larger in cross session, hence have 1.29 times the diameter, requiring more insulation, more steel, more oil. In other words, copper conductor can save 22% (=0.29/1.29) on materials surrounding the conductor. High conductivity means low resistance lower losses.
2) High thermal conductivity: The copper is also a material of choice for highly efficient, compact heat exchangers for use in refrigerators, heat pumps, air conditioning equipment, solar thermal panels, district heating systems or industrial applications.
3) Mechanical Property: Good mechanical properties such as creep and fatigue resistance make copper perform in electrical contacts.
4) Malleability: Copper can be drawn into wires as tiny as 50 microns (half the diameter of a human hair).
5) Corrosion-resistant: Therefore, it is used for several hundred years in outdoor applications without corroding. It is also used for this property in marine applications, in demanding chemical environments, for high integrity earthing systems or for bare overhead conductors in coastal regions.
6) Easily alloy able: That means improved strength, corrosion resistance, micro-alloys for high strength and conductivity, wear resistance, machinability or heat resistance.

Characteristics that make copper Unique:

1. Copper is the best electrical **conductor** among all metals.
2. Copper has global **eco-system** of 100+ interconne-cted smelters to manage the

flow of primary and secondary raw materials

3. The use of copper is deeply linked to the world's **energy** system. Copper is key to achieving energy and climate objectives.
4. The mining of copper contributes knowledge to other fields such as **geo-logy** & civil engineering.
5. The copper sector has a **geographically** dispersed production system over 87 countries. According to World Mining Data 2021, its production is the ninth most dispersed among 60 minerals, and the second among all metals (after gold).
6. Copper is one of the seven metals of antiquity. Copper is probably the **first** metal ever used by mankind. It has a **history** of 10 millennia associated a rich culture & folklore.
7. Copper's **life-cycle** dynamic relates to its use as the conductor of choice in the energy system. Once produced, copper produces significant benefits in use through its long lifetime. And through recycling, copper can go through many lifetimes.
8. Copper is very **long-term** business. The lifetime of a large-scale mine, from exploration to rehabilitation, can take over a century. Very few processes in the worlds of technology, policy and markets need to take such a deep time perspective.
9. As the third metal, copper is a base metal, but it also displays some characteristics reminiscent of **precious** metals.
10. Copper's **properties** make it a high-tech material once it's been mined and refined. At a result, over 80% of copper is used in its unalloyed form. In contrast, well over 90% of other metal use is primarily in alloyed forms.
11. Not only is copper predominantly used in its unalloyed form, it also has electrochemical properties that allow to **recycle** it without loss of property and it can even be upcycled. In addition, copper smelters can recycle over 20 other materials.
12. However, considering copper's predominantly sulphide ores, at low grade and copper's high production volumes, copper mining carries a significant **risk** that needs to be carefully managed.
13. Considering its volume in use, and its semi-precious nature, copper has a large footprint in primary material moved and **tailings** produced, as well as significant **water** footprint.
14. Copper's **ubiquity** is a characteristic that it probably shares with other materials such as steel, aluminium, chemicals and plastics. However, as a conductor that transports electricity and heat, or as a conductor that produces rotating magnetic fields in electric motors, or generates electricity from rotation in wind turbines, copper is quite literally *"the metal that runs the world"*
15. No galvanic action
16. Lower level of creep

17. Less prone to failure
18. Less expensive to manufacture
19. Smaller & lighter
20. High value of copper scrap

COPPER & ALUMINUM:

i) A Comparison of Life-Cycle Cost:

The total cost of ownership (hereafter called life-cycle cost) not only takes into account the initial cost, but the costs to operate and maintain over its lifetime, and thus includes both CAPEX and OPEX. This makes it possible to calculate the real economic choice between different conductor materials, such as copper & aluminum. Typical areas of expenditure which are included in an LCCA include purchase cost, operation and maintenance, residual value, electric losses, and costs of disposal. All costs are discounted and totaled to a present-day value; known as the Net Present Value (NPV). During LCCA of 20kV, 110kV & 400kV cable it is found that there is minimal difference (on average 3%) in total life-cycle costs between copper and aluminum conductor cables over their operational lifetime. Hence, with use of aluminum so many above benefits of copper are discounted.

Copper can withstand higher stress levels for longer durations than aluminum. the comparative values of fatigue strength for high conductivity copper and low alloyed aluminum.

Table 1

Material		Fatigue strength N/mm^2	No. of cycles x106
HC Aluminium	Annealed	20	50
	Half-hard (H8)	45	50
HC Copper	Annealed	62	300
	Half-hard	115	300

ii) CREEP resistance – a design parameter for Distribution Transformers:

As a metal, Aluminum and Copper has different creep resistance. The steady state creep rate is the important parameter in view of life of the DTs. The steady state creep rates for EC grade Aluminum and electrolytic Copper wires are as per table (2). At high temperature, diffusion becomes very active which accelerates plastic deformation due to recovery which in turn increases steady state creep rate and tendency to early rupture of wires.

Table 2

Temperature (°C)	Stress (MPa)	Steady state creep rate (per hour)	
		EC grade Aluminum wire	Electrolytic Copper wire
100	40	5.34×10^{-6}	0.26×10^{-6}
100	65	18×10^{-6}	0.5×10^{-6}
140	40	25.3×10^{-6}	3.5×10^{-6}
140	65	79.3×10^{-6}	6.9×10^{-6}

The steady state creep rate for EC grade Aluminum wire is found more than that of electrolytic Copper wire under similar operating temperature and stress conditions which in turn leads to the fact that aluminum gets fractured earlier than copper. This is the reason for early failure of the Aluminum wound DTs than Copper wound DTs.

Creep and fatigue in HT winding conductors greatly affect the performance of the transformers. Therefore, it can be seen that the life of the Copper wound distribution transformers is found more than Aluminum wound distribution transformers.

NEW APPLICATIONS:

1) Active Repairs of distribution transformers: In the active repair the aluminum windings are replaced by copper winding to get the benefits of enhanced life, increased capacity, enhanced short circuit capacity, lower losses, compact design, averting substation augmentation, etc. Improves energy performance and lowers lifecycle costs.
2) Earth mesh: The substation earth mesh is normally made with GI steel. Earlier also the copper was used, and the strips were buried to form a required section of earth mesh. The numbers of grid sections get reduces as compared to Aluminum. However, due to threat of theft the practice discontinued. But, considering Life cycle cost, copper is found to be more significant over long life of substation. Nowadays there are so many avenues to safeguard the copper buried in ground and the benefits of higher mechanical and electrical strength of copper can be availed.
3) Building installations: As per comparative evaluation of wires and cables used in building installations with copper and aluminium conductors w.r.t. ampacity, thermal capacity, weight, size, strength, ease and reliability of installation, reliability of connections and terminations, corrosion aspects and relative costs, it is seen that in each respect, copper conductors out-perform aluminium conductors for all wire and cable types used within buildings.

Characteristic	4 core x 95mm² XLPE/SWA PVC Copper Conductor	4 core x 150mm2 XLPE/SWA/PVC Aluminium Conductor
Current Carrying Capacity (Ampacity)	304 Ampères	305 Ampères
Cable Weight kg/m	5.51 kg/m	4.5 kg/m
Cable Diameter mm	37.7 mm	47.9 mm
Bending Radius (minimum multiple of diameter)	X 8	X 10
Minimum Bending radius (mm)	302 mm	479 mm

Table 4 – Cable Properties Comparison for equal ampacity (4)

Characteristic	Copper	Aluminium
Weight for same conductivity (Comparative)	100	54
Cross section for same conductivity (Comparative)	100	156
Tensile Strength Annealed (N/mm^2)	200	50 - 60
0.2% Proof Stress Annealed (N/mm^2)	≤ 120	20 – 30
Tensile Strength Half Hard (N/mm^2)	250	85 – 100
0.2% Proof Stress Half Hard(N/mm^2)	≤ 180	60 - 65
Tensile strength for same conductivity (Comparative)	100	72
Mass density g/cm^3	8.91	2.70
Thermal expansion rate/K	17×10^{-6}	23×10^{-6}
Temperature for creep of 0.022 %/1000h under typical termination stress	150 °C	20 °C
Cold Flow/Hardness (Elastic Modulus) – kN/mm^2	130	70

Table 3 – Physical Properties of Copper and Aluminium (3)

CONCLUSION:

Copper seems to be super material for electrical engineering having so many benefits and superior properties as compared to aluminum having advantage of low cost. On long run the use of copper proved to be justified and advantageous.

Mega trends, such as the energy transition, digitalisation and sustainable development, are expected to result in significant demand growth for copper.

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He is associated with various technical organisations like CBIP, IEEMA, SPE, CEA, ERDA, CIGRE etc. He is member to NSC B1, B2, B3, A2 & A3 of CIGRE and ETD16, ETD30 & ETD34 of BIS committees.

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EFFECT OF MARINE ATMOSPHERE ON THE METALLIC COMPONENTS OF DISTRIBUTION NETWORK

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1. Gujarat is a state in western India. It has an area of 203,800 Sq. kM with a coastline of more than 1,600kM. Most of coastal areas lies in Kutch, Saurashtra and South Gujarat regions of the State. The state is bordered by Rajasthan to the north, Maharashtra to the south, Madhya Pradesh to the east, and the Arabian Sea as well as the Pakistani province of Sindh on the west. A map showing Coastal Lines is exhibited below:

Gujarat is one of the 8 Eco regions of the state covering 14% of the geographic area. The state has 13 coastal districts and 39 coastal talukas. 38% of the coastal area falls in the Kutch district, followed by Jamnagar (17%), Junagadh (9%) and Bhavnagar (9%). and Valsad (3%).

2. The consumers in the coastal areas are experiencing momentary power interruptions caused by salt contamination on the utility's power lines. The salt contamination of the power lines and equipment is caused by prevailing winds bringing salt-laden air from the sea. The combination of salt and moisture can cause arcing, sparking, blown fuses, pole fires and extensive power outages. Utility crews are using pressurized water hoses to wash the salt from lines and equipment today.

3. Kutch and South Gujarat regions of the state are major salt production hubs and have a highest salt export potential in the country. The Distribution Network laid in the salt pans suffer heavily and require frequent maintenance, failing this the interruption in power supply is inevitable.

The Distribution Network in the state comprise the following:

- 11kV AB Switch.
- 11kV Single Circuit/ Double Circuit line comprising PSC Poles/ Girder Poles, Insulators and Conductors.
- Distribution Transformer Centre comprising Distribution Transformer (ranging from 5kVA to 500kVA), Distribution Box with CB, Transformer Supporting Poles (PSC or Girder), Angles, D.O. Fuses, Earthing, LT Cables, LT Fuses, etc.
- 415V Distribution Line (LT) comprise PSC/ Girder Poles, LT Conductors with accessories, Insulators with Hard-wares, Stay Wire, Earthing, etc.
- Service connection comprise LT Fuses on Pole or MCC insulated Service Wire, Reel Insulators, Supporting Wire, etc.
- The last Distribution Installation is Consumer Energy Meter.
- In case of HT Consumer CT/ PT Unit and Tri-vector meter is the terminal unit.

4. The region of Kutch and North Gujarat (Palanpur, Dessa, etc.) experience dust storms in the months of April, May and June. In the event of such windstorm, the visibility becomes very poor. The micro fined dust deposit on the Distribution Network components. In the Kutch, Saurashtra and North Gujarat region the evenings are very cool and moisture deposit on all the components of distribution Network. The Distribution Network which is in the salt pans and in proximity to the Ocean suffer from the following damages:

a. Due to cool wind flowing at moderate velocity throughout the year, the PSC poles develop stress. This results into capillaries along the length of the pole. The saline water run from bottom to top from such capillaries and destroy the reinforcement of the PSC poles by heavy rusting and pitting. The PSC poles break into pieces.

b. All the items of Distribution Transformer Centre indicated above are subjected to heavy rusting and pitting. Many times, the transformer centres collapse along with the PSC Poles or the Girder Poles.

c. In many cases the steel core of ACSR conductor suffers from heavy corrosion and ultimately breaks to pieces and the aluminium stands are not able to take the tension. This destroys the conductor. In case of All Aluminium conductor, the salinity in the oceanic climate results into heavy oxidation of aluminium material and conductor starts reducing to a powder form.

- **d.** Due to oxidation heavy sparking are being observed on all the live parts. This causes a breakdown.
- **e.** The Service Connection wires, the supporting GI Wires, switch gears and meters suffer from heavy rusting, pitting and holes in the metal sheets.
- **f.** Due to oceanic climate the corona is also very predominant and causes power loss coupled with sparking can cause breakdown.

5. The remedial measures taken by the DISCOMS for above eventualities are as follows:

- **a.** Ordering the Distribution Transformers with PU paints.
- **b.** Applying bituminous paints on the bottom portion of PSC/ Girder poles.
- **c.** Regular painting of the ferrous components of the Distribution Network.
- **d.** Condition Monitoring of conductor, insulator and hard wares.
- **e.** Condition monitoring of Earthing System.
- **f.** Replacement of Service Line Wires and support GI Wires where extensive damage is observed.
- **g.** Access the residual life of equipment and strengthen it. One can apply here metallurgy testing i.e. Distractive and Non–Distractive.

i. Visual Inspection:

Visual Inspection can be conducted for deformation, welding defects and corrosion using ruler, gauges, cameras, etc. This will indicate the quality of material.

ii. Thickness Gauging:

Measure the thickness of the component of equipment. Ultrasonic Thickness Gauge is a method that evaluates the thickness of a component by measuring the time it takes for sound to travel from the transducer through the material to the back end of a component, and then measures the time of reflection back to the transducer, the gauge then determines the thickness based on the velocity of sound through the material being tested.

iii. Patrolling by use of Drone:

The latest method of condition monitoring is use of drone for patrolling of Distribution Network. The images captured in drone very precisely indicate the damage caused to each component of Distribution Network.

Some photographs are exhibited below:

Few Photographs Showing
Damages to Components in Distribution Network

6. Due to the Power Re-form in vogue from the year 2003, the DICOMs are responsible for keeping high availability of the Network and also the consumer satisfaction. Therefore, the DOSCOMs in Gujarat are spending a lot on the Operation and Maintenance of Distribution Network in the Coastal Region.

7. Use of GRP/ FRP Poles in the oceanic climate can reduce the outage on account of support failures, to a great extent. GRP/ FRP poles are also supplied with insulated cross arms made out of similar material.

8. In some part of South Gujarat, it is observed that the sea is changing its coastal line and hence the Distribution Lines and Distribution Transformer Centers come very close to the coastal line.

9. Mitigation:

The utility has to replace the material periodical when it gets affected by Coastal Saline Environment. The utility has replaced following materials during 8 years and observed reduction in interruption:

- 40,000kM Over Head Conductor
- 90,000 Steel Pole
- 45,000 Insulators
- 22,000 Distribution Boxes
- 17,000kM of Cables
- 4,000 Distribution Transformers, and so on. . .

10. Conclusion:

1. The distribution network in coastal region of Gujarat State suffers from heavy damage due to saline atmosphere and salt pans.

2. This DISCOMs in the states have to be on alert all the time to minimize outages.

About Authors

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Graduated in Electrical Engineering from MS University, Vadodara in 1971. He joined Gujarat Electricity Board in 1972 as a Junior Engineering and retired as a Chief Engineer (Transmission) in 2006. During his tenure of 34 year he worked in Distribution, Generation and Transmission Department. Most of his tenure was in Transmission department. A Member of Bureau of Indian Standards (BIS) and Central Board of Irrigation and Power (CBIP) for Transmission line and Substation related committees. He is recipient of several Awards for R&D and has contributed to the Transmission Segment. At present he is a Managing Director of M/s Takalkar Power Engineers and Consultants Pvt. Ltd. Vadodara. The firm offers services of Electrical, Civil & Structural Engineering Designs, Energy Management, Project Monitoring and Energy Audit**. M 9925233951 9879599402**

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Er. SP Trivedi

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METALLURGY IN POWER SECTOR AND INDUSTRIES

Er. YS Trivedi
Retd. Sr. VP & Advisor L & T

Materials technology has driven breakthroughs and efficiencies for thermal power sector for the last five decades. We have grown on high temperature, corrosion resistant and abrasion resistant steels C-Mo, Cr-Mo, Cr-Mo-V, SS 304/309/316/321/347, 17-4-PH, Stellite, X13Cr MoV, High-Mn Steels and many more. It would be superfluous to discuss them today with all of you who are experts.

Within the next decade all these will undergo complete transformation and we need to prepare for those challenges. I would like share my perspectives on the materials for the followings:

4. Nuclear Energy

a. PHWRs natural Uranium Reactors 700 -1000Mwe
b. Light Water Reactors 1000 - 1600 Mwe
c. Fast Breeder Reactors – 500 Mwe
d. Thermonuclear Fusion Reactors
e. Materials
   i. Inconels – Tubes and overlays
   ii. Titanium and their alloys
   iii. 22MnMoNi55 and super heavy forgings
   iv. Lean Cobalt SS Materials and heavy forgings.

   i. Superconducting Magnets (4.2^0K)
   ii. High Temp alloys
   iii. Single crystal components

2. Hydrogen as an alternate to fossil fuels / hydrocarbon

a. Production of Hydrogen
   i. Fossil Fuels – Methane/ Coal- steam reforming
   ii. Electrolysis – solar/wind/geothermal/ hydro-fossil fuels/biomass/nuclear Grey – Blue – Green Hydrogen
b. Fuel Cell – H from Sr 2a and ‘O’ from air – Platinum Group of Metals – Pa, Pt, Pd, Rh, Ru, Ir, Os
c. Materials
   i. High Temperature reformers
   ii. GTL and Coal Gasification Materials
   iii. Platinum, Nickel, Chromium
   iv. Platinum Group of Metals
   v. Palladium and their silver alloys

3. Mega Watt energy storage – Lithium-Ion Batteries, high energy storage capacities – 100 -200 MWe

a. Fast charging
b. Stable deliveries

f. High energy densities – large capacities
g. Longer durability
h. Improved safety
i. Charging Cycles
j. Grid stabilising capabilities
h. Materials
   i. Niobium and its Ti/W oxides Anodes - multivalent / diverse lattice configurations / structure directing agents/ Fast Charging / Thousands of cycles of charging / Super capacitor capabilities
   ii. Nickel – replacement of Co – doping with Nb – stabilising and passivation

5. Superconducting Magnetic Energy Storage SMES

a. No current decay
b. Energy can be stored indefinitely
c. Instant Power availability
d. High power output
e. Ultraclean power for Thermonuclear fusion and semiconductor plants
f. Present capabilities – 100 MWE
g. Materials
   i. High temperature super conductors HTSC 77^0K
   ii. Medium Temp SC 20^0K
   iii. Low Temp SC LTSC 4.2^0K
   iv. Carbonaceous Sulphur Hydride - + 15^0C @ 267 GPa
   v. Cuprates – Cu oxides with spacer layers of Lantha-num, Ba, Strontium

6. Summary: Complete material spectrum will change in the next decade and today is the best time to prepare and take the lead in technology.

We need to introduce new super-speciality courses in our institutes, sponsor research projects, participate in techno-logy development with leading players, manage technology collaborations and be prepared for stable, economical and greed power!!

VIEW OF METALLURGY IN POWER SECTOR

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ABSTRACT:

In this overview, base is (not metallic component wise) only main units of all three basic sub-sectors i.e. Generation, Transmission and Distribution. Overview is qualitative (not quantitative) comparison of issues between the mentioned main units.

Metallurgists are mother of engineering sector. The very first-step of selection of Metal for making MCs is metallurgical engineering exercise. In this study (overview) Metallurgy always includes necessary WELDING and NDT/NDE.

In addition to Generation, Transmission and Distribution sub-sectors, two more equally important associated sub- sectors are manufacturer of power sector components/equipment/units and technical service providers.

Service conditions are quite more severe in MCs of Generation sector than in MCs of Transmission & Distributions sectors. Among Generation sectors, service conditions of Mcs of Nuclear plants are extremely sevse. Highly severe in Thermal plants and minimum is in that of Hydro plants (because they work at room temperature).

In thermal, among turbines, Service conditions are quite more severe in Mcs of Gas turbines than in turbines. In thermal, among boilers, severity of service condition of MCs, in increasing order is heat recovery, waste heat recovery, lignite fired fluidized bed, lignite fired conventional (burner type), sub-critical pulverized coal fired conventional and super-critical conventional pulverized coal fired. Severity increases with temperature increase.

Transmission and Distribution sector extensively use structural steels and extensive welding is used in boilers.

With respect to need of specification of metallic components, issues involved in getting metallic components before and O&M stages are discussed for entire power sector. Failure analysis is necessary for failing component.

For metallic components undergoing In-Service-Degradation, their identification and periodic examination for damage assessment is necessary. Condition Assessment and RLA nothing but this periodic examination.

Power sector can and is running very well without metallurgical engineers. Though small, experience of power companies having their own metallurgical engineers, do suggest that presence of in-house metallurgical engineers is beneficial to power generating follow the path and enjoy benefits.

1) About Overview

Metallurgical issues are associated with each MC (metallic Component). Even in a small sub-station it is almost impossible to prepare list of all Mcs used. Because gigantic number of MCs are there in entire Power Sector, component wise discussion is impossible.

Therefore, in this overview, base is only main units of all three basic sub-sectors i. e. Generation, Transmission and Distribution.

Difference between Transmission and Distribution sectors is in agencies from where power is received and whom power is delivered. In Transmission sector, receiving end is Power Generating plant and delivery end is Sub-station/s, whereas in Distribution, receiving end is sub-station and delivery end is power consumers. Otherwise, technically their units, their functions are same. Therefore, in this overview they are clubbed together for showing main units.

In Overview, comparison among units is qualitative (not quantitative).

2) General aspects of Metallurgy and Power Sector

2.1 General aspects of Metallurgy (Metallurgical Engineering)

a) More than 80% components Industrial (Engineering) sector have, are metallic, i.e. Engineering sector is nothing but MCs (Metallic component). Now, it is fact that behavior of children is best understood by their mother. Similarly, "behavior" of MCs is best understood by metallurgists. Thus, it may be said that "Metallurgists are mother of engineering sector".

b) Can anyone (irrespective of whether it is industrial sector or domestic sector or any sector) make MC without selecting metal for it? No. Selection of Metal for making MCs is very first exercise of design of MCs. This very first-step is metallurgical engineering exercise.

c) Single Mc is usually not used. Generally, they are used as "assembly of MCs". This assembling is done either by fasteners (Nuts, bolts, rivers, wedges etc.) or by welding (assembly is called WELDMENTS) or both.

d) In this study (overview) Metallurgy always includes necessary WELDING and NDT/NDE.

2.2) General Aspects of Power Sector:

a) Sub-Sectors of Power Sector

SUB-SECTORS OF POWER SECTOR					
MAIN SUB SECTORS				ASSOCIATED SUB SECTORS	
GENERATION		TRANSMISSION	DISTRIBUTION	MANUFACTURERS of Metallic Components / Equipment / Units	SERVICE PROVIDERS A. Met Testing Lab. B. NDE Services, C. Failure Analysis D. CA E. RLA F. Consultants
Conventional Hydro, Thermal Nuclear	Non-conventional				

Many technical persons believe that sub-sectors of power sector are only, Generation sector, Transmission sector and distribution sector. However, two more equally important (may be called associated sub-sectors) sub sectors are manufacturers of power sector components /equipment /units and technical service providers (generally for components in use). These service providers include

1) Metallurgical Testing Labs
2) NDT/NDE Services
3) Failure Analysis agencies
4) Condition Assessment agencies
5) RLA agencies and
6) Consultants.

a) Main units of main sub-sectors of power sectors (as viewed by authors).

MAIN UNITS of MAIN SUB SECTORS of POWER SCTORS			
TRANSMISSION & DISTRIBUTION	Transmission and Distribution sub sectors		Switch yards (Structural steel structure, & required fittings)
			Switch gears in control room
			Transformers
			Transmission Towers
			Transmission conductor cables
GENERATION (Conventional)	Nuclear Generation sub sector		Nuclear Reactor
			Heat Recovery Boiler
			Steam Turbine
			Generator
	Hydro Generation sub sector		Penstock
			Hydro Turbine
			Generators
	Thermal Generation sub sector	Boiler	Boilers (combustion) or
			Fluidized bed Boilers or
			Heat Recovery Boiler or
			Waste Heat Recovery Boiler or
			Super critical Boilers
		Turbine	Steam Turbines or
			Gas Turbines

		Generator	Generator
		If coal/ lignite is fuel	Coal & Ash handling plants
GENERATION (Non-Conventional Alternate, Renewable Energy Sources)	Wind, Tidal, Solar, Biomass, Geo- thermal, Green Hydrogen, etc. Metal/metal compound for power storage BATTERIES is main metallurgical issue		NOT INCLUDED IN THIS OVERWIEW

3) <u>Overview with respect to Severity of Service Conditions</u>:

Important Note: About Generators and Conductors

Big size generators use H_2 gas as cooling medium whereas small size hydro units use air cooled generators. It is a fact that except solar generation system, all generation systems use one or other type of generator. However, because of limited knowledge of author, <u>comments for Generators are avoided</u>

Three types, if conductors are used in power sector.

1) Conductors in transmission cables (mainly aluminum without insulation with steel reinforcement)
2) Conductors in wiring (generally with insulation) and
3) Conductors as coils in motors, generators and transformers. There are 3 presentations in this conference. Hence <u>conductors are not discussed in this overview</u>.

Simple, Significant, High, Very High and Extremely High are levels of SEVERITY OF SERVICE CONDITIONS, in increasing order. Severity of Service Conditions, of all main units is shown in the following TABLE.

Main Units of sub sectors of Power Sector		Severity of Service Condition
Transmission and Distribution sub sectors	Switch yards (Structural steel structure, and required fittings)	Simple/ Little
	Switch gears (in CR)	Simple/ Little
	Transformers	Simple/ Little
	Transmission Towers	Simple/ Little
	Transmission conductor cables	No Comment
Nuclear Generation sub sector	Nuclear Reactor	Extremely High
	Heat Recovery Boiler	Simple/ Little
	Steam Turbine	High
	Generator	No Comment

Hydro Generation sub sector	Penstock		Simple/ Little
	Hydro Turbine		Significant (if silt related problems)
	Generators		No Comment
Thermal Generation sub sector	Boiler	Boiler (Combu-stion) or	Signi-ficant
		Fluidized Bed Boilers or	Signi-ficant
		Heat Recovery Boiler or	Simple/ Little
		Waste Heat Recovery Boiler or	Signi-ficant
		Super Critical Boilers	High
	Turbine	Steam Turbine or	High
		Gas Turbine	Very High
	Gene-rator	Generator	No Comment
	If coal/lignite is fuel	Coal handling plant, Pulverizers and Ash handling plant	High

Summary: (1) Service conditions are quite more severe in MCs of Generation sector than in MCs of Transmission & Distributions sectors (2) Among Generation sector, service conditions of Mc of Nuclear plants is extremely severe, highly sever in Thermal plants and minimum is in that of Hydro plants (because they work at room temperature). (3) In thermal, among turbines, Service conditions are quite more severe in MCs of Gas turbines than in Steam turbines (4) In thermal, among boilers, severity of service conditions of MCs, in increasing order is heat recovery, waste heat recovery, lignite fired fluidized bed, lignite fired conventional (burner type), sub-critical pulverized coal fired conventional and super-critical conventional pulverized coal fired. Severity increases with temperature increase.

Selection of metal and all other metallurgical matters for MC mainly depends on Service conditions the MC is going to face while in use/operation/ service.

Higher grade of metal is necessary with higher severity of service conditions. Metallurgical "concerns" about MC, increasing with increase in severity of service conditions.

Naturally, Metallurgical matters are most serious with Nuclear reactors than all other units in power sector.

4) Overview with respect to welding and need of special metals.

During making of assembly (weldment) / equipment / unit / plant, weldability of MCs and amount of their welding is very important factors Welding aspect of all main units of main sub-sectors is shown in following TABLE.

Need of special metals is also covered in this 'table'.

Special Materials and Welding Aspects of Main Units of sub sectors of Power Sector		
	Main use of sub sectors of Power Sector	Special Metals and Welding Aspects
Transmission and Distribution sub sectors	Switch yards (Structural steel structure and required fittings)	Extensive use of Structural Steels and fasteners
	Switch gears (in CR)	Material & Welding are SIMPLE
	Transformers	Material & Welding are SIMPLE. Special steels are used for core
	Transmission Towers	Extensive use of Structural Steels and fasteners
	Transmission conductor cables	No Comment
Nuclear Generation sub sector	Nuclear Reactor	Special metals are necessary
	Heat Recovery Boiler	Extensive Welding
	Steam Turbine	Special metal for Blades and special assembly of diaphragms on shaft
	Generator	No Comment
Hydro Generation sub sector	Penstock	Welding little difficult (big opening at top and small opening at bottom). For low Temperature Ni having Steel used.
	Hydro Turbine	Special metal for blades. Other material & welding are SIMPLE
	Generators	No Comment
Thermal Generation sub sector – *Boiler*	*Boilers (combustion)*	*Extensive Welding and creep resistant steels are used*
	Fluidized bed Boilers	Extensive Welding and creep resistant steels are used
	Heat Recovery Boiler	Extensive Welding and creep resistant steels are used
	Waste Heat Recovery Boiler	Extensive Welding and creep resistant steels are used
	Super critical Boilers	Extensive Welding and highly creep resistant steels
Thermal Generation sub sector – Turbine	Steam Turbines or	Special steel for Blades and special assembly of diaphragms on shaft
	Gas Turbines	Very special metal for Blades with air cooling provision

If coal / lignite is fuel	Generator
Coal handling plant, Pulverizers and Ash handling plant	Generator
Abrasion and erosion resistant materials & metals	No comment

In case of transmission and distribution there is mention of extensive use of “structural steel” and in case of boilers about “extensive welding”. Both of these aspects are discussed.

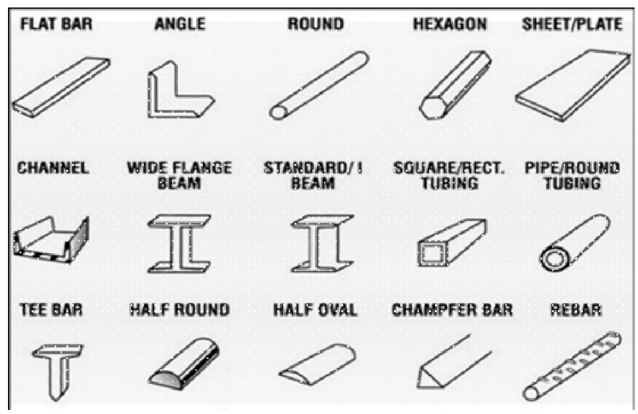
4.1) **About Structural steels:**

All industrial equipment need sound supports (or Foundation). Equipment like transmission tower, big size turbines, genera-tors, ID and FD fans, coal pulverizes, cooling water pumps etc. are having RCC foundation.

However, a number of equipment’s are positioned and supported by structural frame-work made of steel in units like boilers. Roof of all big size workshops are supported by structural frame work made of steel. Transmission towers and switchyards and are nothing but supporting structure made of steel. Transmission towers and switchyards and are nothing but supporting structure made of steel. In these supporting structures, the steel used are called “Structural steels”. They are steels having shapes of C-channel, I-channel (beam), angles etc.

These and other generalized/ simple shaped steel components, like plates, bars, sheets, rods, wires, pipes, tubes, are called “Structural Steel”.

In facts all metals are basically available in generalized simple shapes like plates, bars, sheets, rods, wires, pipes, tubes, C-channel, I-channel (beam), angles etc. and are called “Structural components”.



These Structural components are basically “WROUGH” products. Liquid metal is solidified as big size Ingots which are then subjected to “multiple” thermo-mechanical (heating and plastic deforming) processes to reduce cross section.

carbon increased and/or alloying elements are added, for improving strength and other properties, their weldability decrease significantly.

Boiler is best example where weldability aspect dominates over service condition aspect.

Extensive welding is involved in making of a boiler of large size (more than 100 TPH of steam). Boilers of 200/210MW have size about 100 x 50 x 150 ft. In such boilers, there is about 300 miles of tubing is present and as a result there are more than 50,000 tube to tube weld joints (they were about 70,000 in old days) and about 150kM length of straight-line welding. In tube-to-tube weld joints, 40% are done at boiler site. With such extensive need of welding, it becomes necessary to have metals with very good weldability. Boiler makers avoid metals having poor weldability even if they are more suitable for service conditions because boilers are to be installed at site within given time.

1) MCs, metallurgical issues and need of Metallurgical Engineers:

5.1) Meeting requirements of MCs before O&M:

No sub sectors (of power sector) make MCs required by them (of course it is not their business). MCs, /equipment / units / plants are made by exclusively power-sector-dedicated manufacturers like BHEL, GE, Thermax or other manufacturers like L&T and there are many other manufacturers.

Power sector (for that purpose, any sector) needs MCs form manufactures, first, at the time of "installation" of component/ plant and then for their replacement, if it becomes necessary. Manufacturers arrange for all metallurgical requirements, necessary for selection of metals (according to severity of service conditions), for making components and their installing at customer's site through their own metallurgists or by out-sourcing. Customers (power sector) need not know 'technical specification' of MCs (in fact, in most of the cases, in power sector, customers do not mention any specification of MCs / plant, everything is in scope of manufacturer).

It may be noted that steel plants are bound to manufacture Structural steels as per Indian standard. Similarly, structural components of all other metals (copper, aluminum etc.) are also covered by Standards. Therefore, power sector is not required to have specification. Thus, the job of procurement of structural steels is simple for transmission and distribution sectors.

Conductivity of conductors very much depends on their metallurgical factors, but their standards are prepared with respect to electrical properties. So far conductors meet electrical requirements there is no need to bother for their metallurgy.

5.2) Meeting requirements of MCs during O&M:

Here again, power sector can get MCs from OEM (who supplied during installation) just by mentioning "product number" (mentioned in the catalogue of spares given by OEM), without bothering about metallurgy (specification) of MCs. Such OEM & customer relations are common.

In contrast, a power generation company, appointed metallu-rgical engineers and told them to prepare specification of MCs required during O&M (after identifying them) as prices of OEM are too high and delivery period is unrealistic (not less than 12 months). As a result, except MCs of turbine and Generator, almost every consumable metallic component is procured from local manu-facturers.

Author is not judging which one is good method, but there is a question, “is it fair that after becoming owner of installed MCs customer is not aware about its specification?”

5.3) About failing components after installation and in-service-degradation aspect:

Replacement of MCs, after their installation, became necessary because they have failed. Are these failures ‘natural’ (as expected) or pre-mature? If, pre-mature (or frequently failing), then, their ‘failure analyses has to be conducted (where awareness of metal specification is desirable).

Quite often failure of MCs is because of wrong metal selection by OEM. It also happens, in such cases, that OEMs never accept their mistake (instead blame users) and do not help in finding right metal. Metallurgical engineer can do this if available.

Many MCs undergo ‘degradation’ during their service period. Such MCs also fails during service if users are not aware about this degradation and their monitoring exercise.

In-service-degradation on account of corrosion and wear (abrasion / erosion) are well known but degradation may also be because of fatigue or creep or both. Awareness about such “in-service-degradation” prone MCs and their periodic monitoring is very important.

Identification of which MC (and in which location in that MC) is prone to in-service-degradation is better done by in-house metallurgical engineers.

When large number of MCs are to be examined for in-service-degradation even power plant metallurgists do not do this job, and they have to outsource work to service providers.

CA, i.e. Condition assessment (metal health monitoring is another name) and RLA i.e. Residual Life Assessment are nothing but other names of examining in-service-degradation prone MCs.

5.4) Need of Metallurgical Engineers:

The jobs, 1] selection of metal (in accordance with severity of service conditions) for MCs, 2] preparation of specification of

MCs, 3] verification of MCs received from local manufacturers, 4] getting Failure Analysis done, 5] correction of root cause of failures (so that similar failures are avoided), 6] identification of in- service-degradation prone MCs, arranging their examination (i.e. CA, RLA) are better done by Metallurgical Engineers.

Though author is not aware about MCs failure problems In Transmission and Distribution sectors, authors is sure that they have many complex problems of failures of MCs. Here also metallurgical engineers can help better. Issue of procurement and use of structural steels is simple. Author recommends periodic use of infrared thermal camera for identifying ‘hot spots’ for switchyards and towers as preventive NDE measure.

In nuclear power generation, boiler, steam turbine and generators are comparatively simpler but nuclear reactor is complex w.r.t. metallurgy. It appears from technical papers presented in conferences of IIM, ISNT, and IIW, in India, that for all nuclear plants, BARC and IGCAR are always available for solution of all their problems. Through these big and sophisticated laboratories all metallurgical (along with NDE and Welding) care is taken. I hope I am not wrong.

As hydro power plants work at room temperature, service conditions are not very severer. However, in rivers flowing in hilly area, turbine blades do face problem of silt erosion.

In thermal power generation number of problems is so large that it is difficult to make their list, particularly in coal / lignite fired boilers. Most sever condition is that of gas turbine.

Unfortunately, Hydro and thermal power plants do not have benefit of availability of dedicated Laboratories (like nuclear power plants).

Metallurgical issues are definitely there in thermal and hydro power plants (problems of nuclear power plant are taken care) and they can be solved by in-house metallurgical engineers or by Metallurgical Laboratories / consultants.

In India, among a very large number of powers generating companies, only 4 thermal companies (2 state owned and 2 private) have their own metallurgical engineers, hence it cannot be said that presence of metallurgical engineers is essential in power generating companies.

However, experience, that too of more than 40 years, do suggest that presence of in-house metallurgical engineers is beneficial to power generating companies and all efforts must be made so that other companies follow the path and enjoy benefits.

2) Conclusion:

Metallurgical issues are there in entire power sector, highest in Nuclear sector, medium in Thermal sectors to minimum in Hydro, Transmission and Distribution sectors. They can be resolved better by metallurgical engineers. In entire power sector, in India, presence of metallurgical engineers is microscopically small. Power sector can and is running very well without metallurgical engineers. However, small, experience of power companies having their own metallurgical engineers, do suggest that presence of in-house metallurgical engineers is beneficial to power generating companies and all efforts must be made so that other companies follow the path and enjoy benefits.

WATERWALL TUBES: UNDERSTANDING THEIR DAMAGE MECHANISMS AND MITIGATION

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ABSTRACT

In coal fired power plants, boiler tubes such as waterwall tubes, super-heater & re-heater tubes and economizer tubes run through several kilometres of distance and are an important component of the entire system. These tubes are exposed to highly adverse conditions in terms of moderate to high skin temperatures, exposure to flame, corrosive and erosive conditions on their outer surface and high- pressure high-temperature water and steam from inside, etc. As a result of this, despite of due care the tubes fail from time to time leading to forced outages and posing huge cost implication on account of frequent tube replacement with direct and indirect economic losses.

Water wall tubes are vulnerable to damages like pitting, under deposit corrosion like caustic gauging and hydrogen attack, hot corrosion and similar other failures. This paper throws some light on failure investigation of water wall tubes based on the thorough metallurgical investigation and critical analysis by subject experts.

Keywords: *Water wall tubes, boiler tubes failure, case studies, failure investigation*

INTRODUCTION

In a thermal power plant the walls of a fossil fuel fired boiler are lined with a network / web of high pressure steel tubes known as ‘water walls’ or waterwall tubes filled with water having diameter typically around 55 to 65 mm. They are installed along the walls, floor and roof of the furnace and either freely exposed, partially covered, or completely embedded in the refractory of the boiler.

A mixture pulverized coal and hot air which is air-blown into the furnace through burners located at corners or along the walls when ignited, results in the combustion of coal forming a large fireball at the centre. The radiations from the fireball heat the water that is circulating through the water wall tubes located along the periphery of the boiler. The water circulating through these tubes absorbs heat and gets transformed into steam essential for running a turbine to generate electricity.

Water wall tubes are usually made of carbon steels or low-alloy steels such as chrome-molly steels. Traditionally plain carbon steels or unalloyed steels are used for handling steam up to a maximum operating temperature of 350^0C. However, carbon steels suffer from their low resistance to oxidation and corrosion at high temperature besides their poor creep strength. In view of this, for relatively higher operating conditions low-alloy steels like T11 and T12 are recommended.

Some of the most frequently noticed reasons for failure of waterwall tubes include stress rupture due to overheating, internal corrosion or water side corrosion such as under deposit corrosion viz. acid phosphate corrosion, caustic gouging and hydrogen damage; oxygen pitting; and external corrosion or fire side corrosion like hot corrosion. Any such failure ultimately affects the performance of the plant by calling for unscheduled forced shutdown. The root cause investigation of tube failures thus becomes essential to restore the boiler back to normal operation and also to eliminate or minimize recurrence of similar failures and the resultant plant outages.

Following case studies on failure of water wall tubes highlight the role of failure investigation in understanding the damage mechanism and underlying root cause of failure.

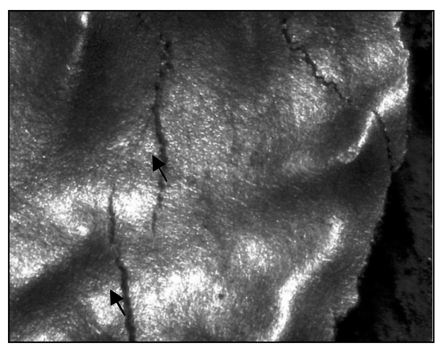
CASE STUDIES

CASE STUDY 1: Failure investigation of HRSG waterwall tube failed due to hydrogen attack

Water wall tube of HRSG boiler failed during operation resulting in a window opening of approximately 125mm length and 55mm width at bend location (Fig. 1(a)). There was neither thickness reduction nor bulging noticed on failed tube and other nearby tubes. MOC of waterwall tube was ST 45.8 III (carbon steel). The tube operating temperature was 250^0C and pressure 100 bar.

Low magnification examination indicated brittle nature of puncture lip with crack initiating from inner surface of the tube. The puncture lip exhibited discontinuous cracks as shown in Fig.1 (b)

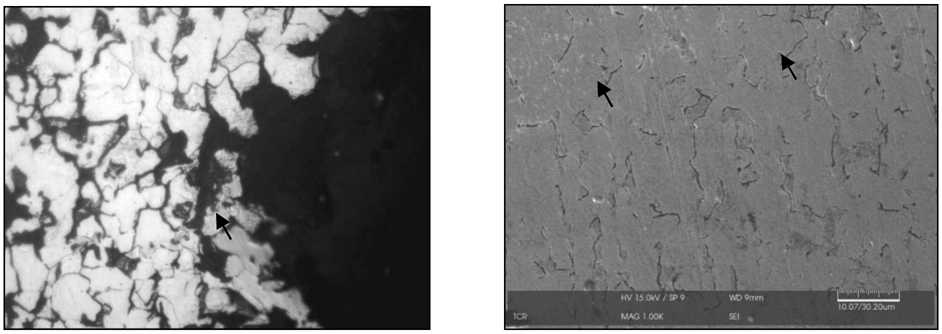
(a)



(b) **11x**

Fig.1: (a) Pictorial view of failed waterwall tube with window type fracture at tube bend and
(b) Inner surface of the tube at rupture location showing cracks

Microstructural examination at the fracture edge showed scattered grain boundary fissures having tendency to form discontinuous cracks (Fig. 2(a)). SEM after metallography showed grain boundary cracks, discontinuous in nature that had formed due to coalescence of fissures (Fig. 2(b)).



(a) 400x **(b)** 1000x

Fig.2: Micrographs showing (a) inner edge microstructure having grain boundary fissures and degraded pearlite and (b) post-metallography SEM image of the sample revealing discontinuous grain boundary cracks

The analysis of all these findings, attribute the nature of failure typically to hydrogen attack. Hydrogen attack is an under deposit type of corrosion of boiler tubes and is characterized by window type fracture and presence of grain boundary fissures. Even a few ppm of hydrogen is sufficient to cause failure of water wall tubes due to hydrogen.

CASE STUDY 2: Failure of waterwall tube due to caustic gouging in a captive power plant

Multiple failures were noticed in water wall tubes after 19 years of service in a single drum natural circulation type boiler used for captive power generation. Type of fuel used was LSHS and phosphate dozing was done at boiler steam drum and hydrazine was fed into the BFW. The MOC of the tube was SA 210 Grade A1 steel. Leakage was noticed in one of the tubes.

Visual examination of the outer surface of the tube sample showed leakage in the form of a linear opening (Fig. 3(a)). The low-magnification examination of the ID surface displayed aggravated metal wastage surrounding the puncture indicating gouging of tube on inner surface (Fig. 3(b)).

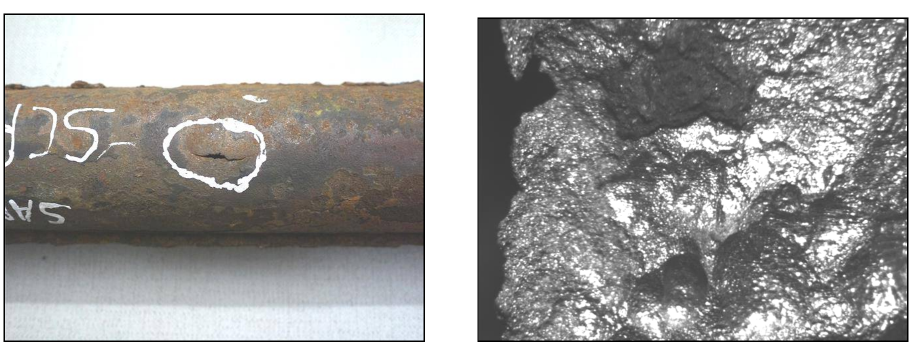
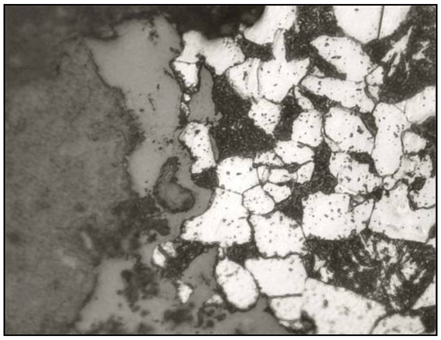
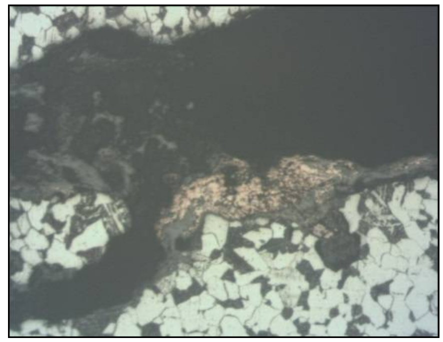
a  **b**

Fig.3: (a) Photograph of the outer surface of the failed tube sample showing a linear crack and
(b) inner surface low- magnification view near leakage location showing metal wastage in the form of gouging

Microstructural examination highlighted thinning at the leakage location essentially from inside where metal wastage had been on account of gouging (Fig. 4(a)). Through and through crack like opening at leakage location with wide, thin and uneven contours filled with oxide scale and copper deposits was also observed.



(a) 400x



(b) 200x

Fig.4: Photogmicrographs showing (a) inner surface with penetration of oxide scale within the matrix of ferrite and pearlite and (b) crack tip filled with oxide scale and copper deposits

The analysis of above findings indicated that the metal wastage by way of corrosion had occurred on account of sodium ion contamination along with other contaminants carried over in the boiler feed water. These evidences coupled with metal gouging as found during low-magnification examination point towards caustic gouging as the damage mechanism.

During caustic gouging the local concentration of sodium hydroxide below the scale deposits is high enough to remove the protective magnetite film. Once the protective magnetite film is damaged, the concentrated sodium hydroxide directly reacts with the underlying metal under high pH conditions. The failure is in the form of distinct hemispherical or elliptical depressions or gouges on the ID side of the tube. The damage occurs especially in the presence of heavy scale deposits on the water side and in high heat flux areas.

CASE STUDY 3: Failure of water wall tube of a waste heat boiler as a result of hot corrosion

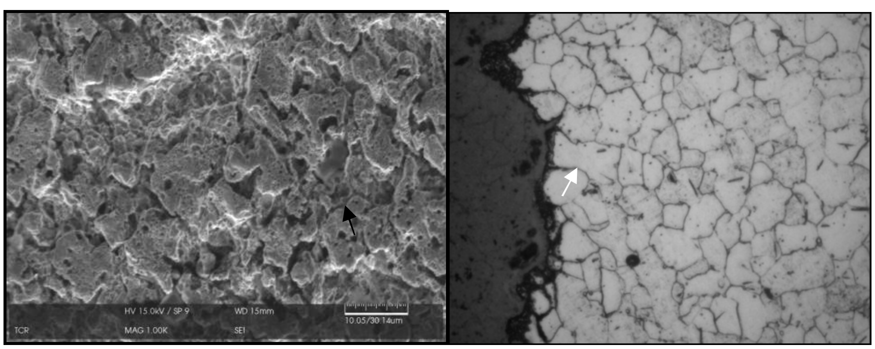
Failure was noticed in the water wall tube in waste heat boiler of fluidized catalytic cracker unit (FCCU) after about seven years of service. The material of construction (MOC) of the tube was SA 210 Gr A1 HFS. Visual examination of the failed sample indicated fish mouth type of opening at failure location having thinned down contours and fine tips (Fig. 5(a)). Metal wastage surrounding the failure location was essentially from outer surface as shown in Fig. 5(b).

(a) **(b)**

Fig.5: Photographs giving (a) close-up view at the failure location displaying fish-mouth type rupture opening and (b) transverse sectional view near failure location showing thinning because of metal wastage essentially from outer surface

Energy dispersive spectroscopic (EDS) analysis on outer surface and scale formed on outer surface showed the presence of elements like oxygen, aluminum, silicon, sulfur, calcium, magnesium, phosphorous, potassium. EDS analysis after metallography on the scale at OD contours confirmed presence of sulphur and phosphorous in the scale.

SEM analysis on outer surface of the tube indicated onset of damage due to intergranular corrosion (Fig.6 (a)). The microstructural examination of the tube revealed the structure consisting of banded ferrite and pearlite. Onset of hot corrosion damage in the form of grain boundary attack all over the outer surface was seen (Fig.6 (b)).



(a) 1000x **(b)** 400x

Fig.6: (a) SEM micrograph of outer surface of the tube sample showing onset of intergranular corrosion damage and (b) Optical micrograph of outer surface showing hot corrosion in the form of grain boundary attack

The EDS analysis indicated presence of potassium and sulfur ions along with moisture based contaminants. The metal wastage on outer surface could be attributed to the formation of volatile sulfur compound in the form of potassium pyrosulfate ($K_2S_2O_7$) having melting point as low as 427 ^{0}C. This leads to formation of molten slag over the tube surface that fluxes the protective magnetite scale promoting accelerated metal deterioration. The metal wastage in turn reduced the cross-section of the tube at the rupture location to the extent that it could hardly sustain the prevailing pressure condition inside the tube leading to failure of the tube under overstress.

The failure of waterwall tube was thus on account of localized metal loss from outer surface due to hot corrosion that had resulted in thinning. Subsequently the tube failed in the form of rupture due to overstress. Hot corrosion is the mode of damage in which boiler tubes experience accelerated oxidation / corrosion when their surfaces are coated by a thin film of fused salt(s) (such as Na_2SO_4 or $K_2S_2O_7$) in an oxidizing gas.

CONCLUSIONS

The investigation of boiler tube failures is mandatory not only from safety and reliability point of view but also from economic view point. The case studies discussed above emphasize the importance of failure investigation in arriving at the root cause of failure of water wall tubes and also in avoiding recurrence of similar failures.

LIFE ASSESSMENT OF BOILER: AN OPPORTUNITY OR COMPULSION

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Abstract

Challenges being face today of Integrating Renewable Energy in GRID, which has entailed the unlearning & relearning of operation of conventional power to balance our growing energy requirements with environmental concerns. Cyclic operation/Load Ramping capabilities of machines of different age and technology posing challenges. Cost of generation has gone high due to less residual life, higher cost of O&M.

In the context of above, role of Metallurgical Engineering is becoming constantly crucial to support by forecasting approach with Knowledge Based Inspection of components, equipment and system vulnerable to Cyclic Loading and perform a realistic life assessment approach rather than conventional.

Remaining Life Assessment of Boiler pressure parts exposed to Cyclic Loading viz. Thick Wall Components, High Temperature Components, Corrosion and Scaling prone Components, Degradation of Insulation due to thermal transient along with Damage Mechanisms causing failure in Boiler tubes and accessories, Turbine blades and components and Chemistry effect has become opportunity rather than compulsion.

This paper reports on the recent developments and opportunity posed to power plants to utilize the modern approach for remaining life assessment to utilize window provided by competent authority and not limit the work profile only to the prescribed guidelines.

1. INTRODUCTION

1.1. The government's new outlook for right to electricity, major policy thrust in coming years could be to expedite generation of electricity. While solar, wind power and other eco-friendly energy sources are sounded widely, the thrust on hydal and more particularly on fossil fuel-based power generation is going to remain for years to come. Hence, while steam generation is put on the fore front, installation and efficient operation of the new as well as existing boilers becomes a matter of paramount concern.

1.2. A large number of power and process plants which were established in the nineteen seventies and early eighties have undergone expected in-served operational ageing and as a consequence are now operating at significantly reduced efficiency and reliability due to frequent breakdowns. The crucial decision whether these plants are to be taken out of service or refurbished to improve their operational efficiency and reliability has to be necessarily based on a rigorous assessment of the present condition and techno-economics of plant sustainability and maintainability, in the future.

1.3. This assessment is typically conducted by undertaking residual life assessment (RLA) not only assesses the present condition of the power plant equipment but also predicts its potential remaining life span. RLA become necessary because in-service components undergo structural & micro-structural damage through thermo-mechanical, electrical, magnetic & chemical interaction with the environment. RLA is mandated for all components, which are designed for finite operational life. The central purpose of RLA is to determine, by accepted methods, the extended duration until which the component can safely remain in service without jeopardizing in any manner the reliability and economic viability of the unit. However, in terms of its common usage, the term RLA covers a wider spectrum of engineering activities used for extending the life of components through renovation and by incorporation of newer technologies. RLA also seeks to take remedial measures so that the unit as a whole operates reliably at a high plant load factor by avoiding/minimizing unscheduled and premature component failures.

1.4. Various tests used for RLA activities include Acoustic Emissions, Fibroscopy, Eddy Current Testing, Ultrasonic (Normal Probe, Shear Probe, Time Of Flight, & Phased Array), Radiography, Magnetic Particle Inspection, Dye Penetrant Testing, Natural Frequency Testing, In-situ Vibration Analysis, Rebound Hardness Measurements, In-situ Replication, Positive Material Identification, Life Estimation Using Characterization Of Microstructure Evaluation and change of Hardness, Carbide Chemistry Evaluation Studies, Fracture Mechanics & Static Property Mechanical Tests, Finite Element Method Analysis and various advanced NDT tests.

1.5. By systematically analysing the results of these tests one can accurately assess the condition of the plant equipment and also estimate its remaining useful life along with its reliability & maintainability.

1.6. The above list of methods/ techniques are widely used during RLA study to have judgement about the residual safe operating life. But it is very important to that which factor is contributing for faster ageing or preventing the Boiler to operate reliably for extended / predicted life. These factors effect various modes of damage mechanisms on various parts/ equipment of Boiler.

1.7. This testing technique determines in-service degradation of critical components of process plants operating under high temperature, high pressure, erosive or corrosive atmosphere.

1.8. It is the essence of RLA to identify the damage mechanism in the Boiler. To identify the damage mechanisms various Non-Destructive and Destructive tests are used. The following table gives idea about the various damage mechanisms and related tools to identify it.

Table 1: Damage mechanisms and related tools

Damage Mechanism	NDT/ DT tool to identify damage mechanism	Related factor contributing the damage mechanism
Erosion	Thickness mapping	• Behaviour of flue gas medium (content, size of the particle, velocity of the medium, mass flow rate etc.) • Alteration in design (spacing / alignment etc.)
Corrosion	Thickness mapping / Destructive test to identify the corrosion	• Change in water chemistry • Improper material selection • Change in the operating environment behaviour
Fatigue	DPT/MPT and FEA to identify the probable high stress location	• Thermal fluctuations i.e. load variations • Restriction in contraction and expansion • In sufficient flexibility in design • Vibration • Uneven temperature distribution

Creep	In situ Metallography / Hardness and Destructive test / Dimensional measurement	• Exposure to high temperature and stress • Improper material selection • Restriction in flow/ partial flow conditions • Improper water chemistry leads scale build up and there is change in the operating metal temperature
Fabrication defects	NDT(MPT/DPT/ UT/RT)	Control over welding processes and inspection of welds.

2. RLA approach

2.1 Based on the analysis of the history of the boiler, it is important to focus the probable locations strategically to ensure the integrity of the component or equipment. Hence selection of the suitable NDT and approach for visual inspection is very important for effective RLA. Where, when and what to see is the significant aspect of any RLA either it is boiler or Turbine or other auxiliaries and that is why this “Significance of knowledge-based inspection in estimating remaining life of the boilers”. This approach is based on the damage mechanism point of view.

2.2. While Indian boiler regulation provides clear cut guidelines for inspection methodology of new and running boilers in amendment-1 2015 13th May and in amendment-2 in 2020, knowledge-based inspection bolsters RLA methodology should be based on actual operating and anticipated damage mechanisms.

2.2.1. Use of in-situ metallography to estimate temperature excursion

2.2.2. Advanced NDT Methods for water wall inspection

2.2.3. In-situ internal oxide scale thickness measurement for re-heater and superheater tubes.

2.2.4. Destructive testing for life Estimation.

2.3. The major boiler components/ pressure parts are classified as under:

2.3.1. Steam Drum

2.3.2. Headers

2.3.3. Pipes (MS line, Super heater, Re-heater…)

2.3.4. Valves

2.3.5. Tubes (Waterwall, Economizer, Re-heater, Super heater, Bank)

2.4. The boiler tubes depending upon the operation zone in the boiler is classified are under:

2.4.1. Waterwall

2.4.2. Economizer

2.4.3. Re-heater

2.4.4. Superheater

2.4.5. Bank

2.5 The possible failure mechanisms in boiler are envisaged as under based on general guide lines. However this will vary as per actual conditions and that needs to be evaluated

Table 2: Damage mechanisms with respect to components

	Creep	Thermal Fatigue	Embrittlement	Erosion	Corrosion
Evaporator		X	H_2	X	X
Drum		X			X
Super heater/ Re-heater tubes	X				X
Super heater headers	X	X			
Re-heater headers	X	X			
De-super heater nozzles	X	X			
Steam lines	X	X			
Feed water lines				X	X

3. RLA assessment

3.1. Salient steps to assess the condition of the boiler components in order to continue stable and reliable boiler operation are:

3.2. Study the remaining life for Superheater and Re-heater by metallurgical inspection

3.3. Evaluation of creep life and future inspection scheme by metallurgical inspection for water wall, economizer, Superheater and Re-heater tubes

3.4. Study degree of creep damage for Superheater and Re-heater by hardness test

3.5. Determine the remaining life based on thickness measurement for water wall

3.6. Evaluate the remaining life based on thickness thinning for economizer due to Low Temperature Corrosion.

3.7. Evaluate the remaining life based on thinning for Superheater and Re-heater tubes due to High Temperature Corrosion

3.8. Confirm the cause of the inner scale generation

3.9. Evaluate the remaining life based on check of metal structure, inner scale etc. for sample tube

Table 3: Inspection for damage assessment

FAILURE	DAMAGE CAUSED	PHENOMENON	LIFE EVALUATION	INSPECTION ITEM
CREEP	Clogging with foreign material Deposition and growth of scale on inner surface Long term stress	Swelling Metal structure change	Outside diameter and thickness measurement Metallurgical inspection	Metallurgical inspection for Super-heater, Re-Heater header Metallurgical inspection and NDT (UT) for main steam pipe line and high temperature RH pipe
Fatigue	Cycle thermal stress	Growth of crack	Stress analysis Surface crack inspection (PT, MT)	Metallurgical inspection for Super-heater, Re-Heater header Metallurgical inspection and NDT (UT) for main steam pipe line and high temperature RH pipe
Corrosion fatigue	Cyclic thermal stress under corrosive environment	Interaction of corrosion and fatigue	Ultrasonic test Sample tube inspection	Sample tube inspection for Super-heater, Re-Heater and water wall Check of Burner Nozzle and Wind Box Damper
Corrosion Erosion	High temperature corrosion Low temperature corrosion Ash erosion	Thickness Thinning	Annual thickness measurement	Measurement of tube thickness for Super Heater, Re-Heater, Water Wall and Econo-mizer by UT Steam drum Boiler aux Eco Hanger tube by endo-scope, etc.

Test Matrix for various Non-Destructive and Destructive tests on various component of the Boiler may be as per following in Table 2

Table 4 Non-destructive test recommended for boiler components.

Sl. No	Component Description	Visual	Ultrasonic Testing	WFMPI +	Liquid Penetrate inspection	Replication	Sampling	Deposit Analysis Scale Measurement	Dimensional Measurement including thickness survey, ovality measurement etc.	Hardness test	In situ oxide scale measurement	Fibroscopy Inspection
1	Boiler Drum	√	√	√	√	√	X	√	X	√	X	X
2	Water Walls (including special bends at PF & oil burner mouth, Peep holes, Man holes, Soot blower)	√	X	X	X	X	√	√	√	X	X	X
3	Water wall Top Headers / Bottom Headers, Up risers & Down Comers	√	X	X	X	X	X	√ Bottom Header only	√	X	X	√
4	Super heater Headers	√	√	√	√	√	X	X	√	√	X	X
5	Super heater Coils	√	X	X	X	X	√	√	√	X	√	X
6	M.S L Piping ++	√	√	√	√	√	X	X	√	√	X	X
7	De-super heater header	√	√	√	√	√	X	X	√	√	X	X
8	Economizer coils	√	X	X	X	X	√	√	√	X	X	X
9	FW piping (including Header Link pipes)	√	X	X	√	X	X	X	√	X	X	X
10	Main Steam line Flow Nozzles Weld Joints	X	√	√	√	√	X	X	X	√	X	X
11	Girth joints, 5% of stub joints of all SH / ECO Headers	√	√	√	√	X	X	X	√	X	X	X
12	De superheater	√	√	√	√	√	x	√	√	√	√	√

The above guideline is generic in nature and test matrix may changes from boiler to boiler depending upon the preliminary / historical review of particular boiler.

4. Advance NDT techniques used for RLA:

4.1. Remote visual inspection of headers Videoscopy:

4.1.1. RVI is the inspection of objects or areas usually inaccessible to the eye without disassembling surrounding structures or machinery. It allows inspectors to discover hidden discontinuities before they may cause major problems, e.g. poor welding, surface defects like ligament cracking, corrosion pits, general condition, degradation, blockages and foreign materials

Photo-1

4.2. PAUT-Phased Array Ultrasonic Testing

4.2.1. PAUT is considered to be accurate for engineering structures due to higher imaging capabilities and processing of signals. Electronic scanning permits rapid coverage of the weld and parent metal. Beam steering and focusing permits the selected beam angles to be optimized ultrasonically by orienting them perpendicular to the defects. Using linear scanning capability of the phased array, the manual and automated motion of the ultrasonic probe during flaw detection is replaced through electronic scanning. This technique is very efficient, that generates more data in relatively less inspection time.

4.2.2. The PA probe consists of many small elements (Figure 1a), each of which can be pulsed separately. In the figure the element on the right is pulsed first and emits a pressure wave that spreads out like a ripple on a pond (largest semicircle).

4.2.3. The second to right element is pulsed next, and emits a ripple that is slightly smaller than the first because it was started later. The process continues down the line until all the elements have been pulsed. The multiple waves add up to one single wave front travelling at a set angle. In other words, the beam angle can be set just by programming the pulse timi ngs; that produce constructiv images on the instrument (Figures 1b and 2

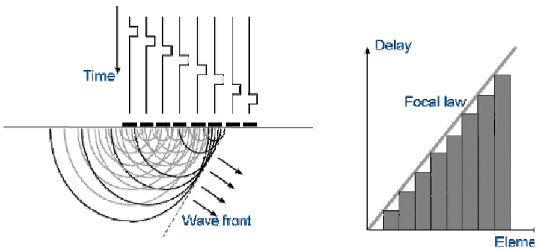


Figure-1(a)

Figure -1(b)

4.3. TOFD-Time of Flight Diffraction

4.3.1. The TOFD technique is based on diffraction of ultrasonic waves at the tips of discontinuities instead of geometrical reflections on the interface of the discontinuities

The differences in the time of flight of the diffracted wave fronts carry the information on the spatial the relationship of the crack tips and hence the extent of crack.

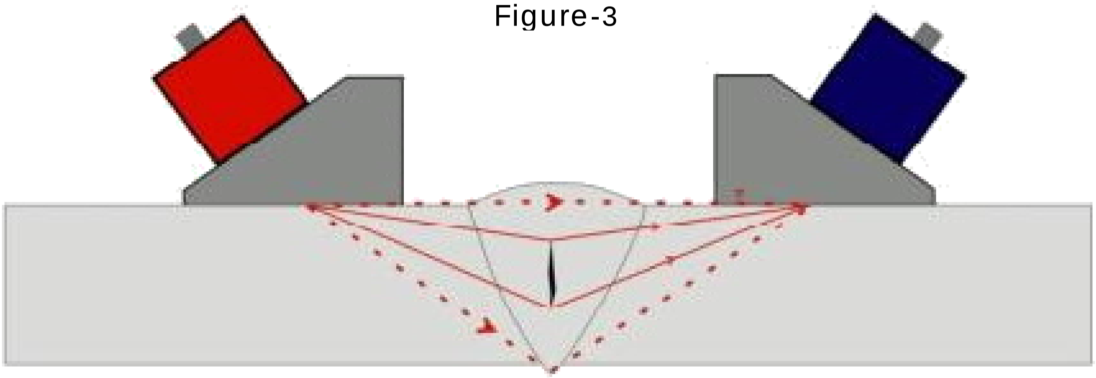
4.3.2. TOFD employs two longi-tudinal wave (L-wave)angle beam transducers arranged symmetrically opposite facing each other, spanning the weld or base material under test (Figure 3).

4.3.3. One probe act like a transmitter of ultrasonic energy while the other probe receives the ultrasound energy.

4.3.4. The transducer, pulser and amplifier characteristics are selected to generate as broad distribution of energy as possible over the material under test providing full weld coverage.

4.3.5. A single-axis scan (that is, along the weld), with a position encoder records the position of the weld and enables the display of digital images in real time.

Figure-3



4.4. High temperature hydrogen attack detection on waterwall tubes (HTHA)

4.4.1. Advanced Back Scatter Ultrasonic Technique (Pattern recognition)

4.4.1.1. The presence of voids is capable of ultrasound beam scattering effect. As the sound scatters, the back-wall reflection energy received gets reduced and thereby indicates increase in attenuation of the material above the area which HTHA above external sidewall of tubes.

4.4.2. Attenuation measurement

4.4.2.1 HTHA will cause dispersion in ultrasonic waves. The drop-in energy of multiple waves of tested area is measured and is compared with drop in energy of multiple waves in virgin material.

4.4.3. Microstructure shows presence of fissures from ID (Figure 4a) due to HTHA which is detected by backscatter ultrasound test (Fig. 4c). The normal beam scatter is shown in Fig.4b for reference.

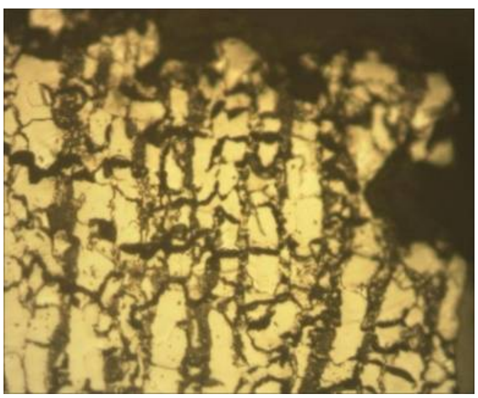


Fig. 4(a)

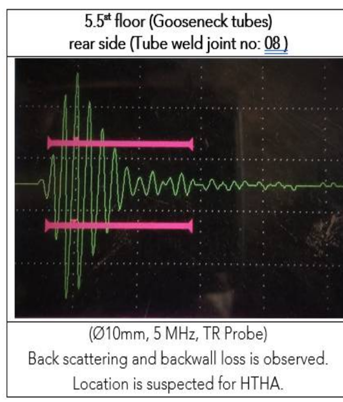


Fig. 4(b)

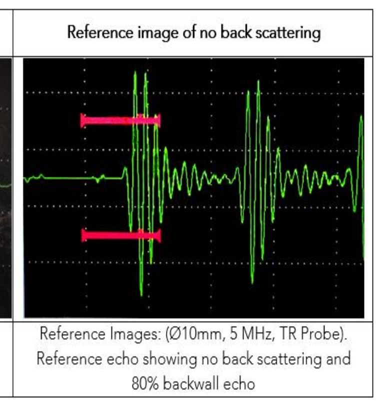


Fig. 4(c)

4.5. RFET (Remote field eddy current testing)

4.5.1. The inspection method employed for boiler tubes was modified RFET (Remote Field Electromagnetic Technology) which is a low frequency AC (electromagnetic) technique. In this technique a signal is sent from an exciter coil(s) to detector coils in which absolute and differential channels. Apart from this, there is Impedance Plane and colour map C-Scan. The signal passes through the tube wall at the crown of the tube near the exciter(s) and returns through the tube wall at the crown of the tube near the exciter(s) and returns through the wall again near the detectors. The time of the flight of this signal is directly related to the thickness of the tube near both the exciter(s) and detectors. The distorted magnetic field is measured in terms of Phase and Amplitude. Phase is related to the depth of flaw and amplitude is related to the size or strength of the flaw.

4.6. EMAT-Electromagnetic acoustic transducer

4.6.1. EMAT – Electromagnetic Acoustic Transducer for the contactless generation of ultraonic waves. An EMAT comprises a magnet and an electrical coil (Figure 5). When a current is passed through the coil, eddy currents are induced in the component under test. The static magnetic field exerts a force on the eddy currents. If the current passing through the coil is an alternating current, then both the eddy currents and the force will change direction with the change in the current. The oscillating force causes the particles of the component to oscillate, generating an acoustic wave which then propagates through the component. For the EMAT to work, the component needs to be electrically conducting material.

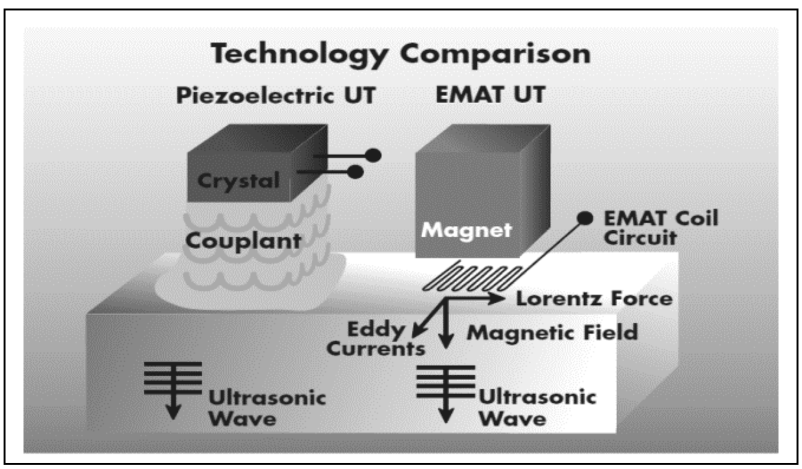


Fig. 5

4.7. Low frequency eddy current testing

4.7.1. A low frequency electromagnetic field in induced into the boiler wall tube material using an external horseshoe shaped electromagnet. Any flaw in the path of the magnetic field distorts the magnetic flux which is detected by the array of sensors (Figure 8). The severity of a discontinuity is measured by analysing a Phase / Amplitude plane graph with the aid of a custom purpose software.

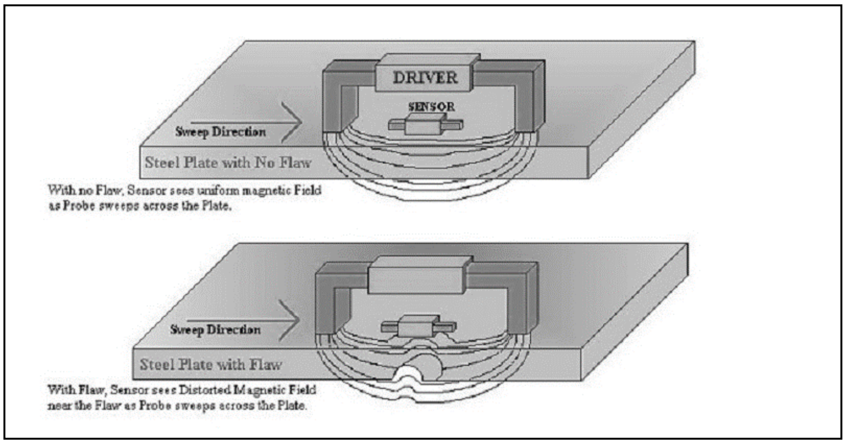


Fig. 8

4.7.2. Inspection of water wall tubes of boiler is carried out consisting of the scanned area corrosion mapping in burner zone, below & above burner zone and goose neck consisting of Front, Rear, LHS and RHS water wall panels. Below 1st image shows the LEFT output of a water wall tube which provides the information of no defect and 2nd image shows the LEFT output of another water wall tubes which consists of a defect of metal loss from inside. It cannot detect defects like lamination and cracks if oriented in direction parallel to the field of magnetic flux. Thickness loss also may not be accurately obtained – advised to carry out follow up UT at suspected location.

4.8. In-situ internal oxide scale thickness measurement and analysis.

4.8.1. Growth of oxide scales is a function of Time and Temperature in continuous operating boiler especially at the heat transfer areas. As the internal oxide scale builds above 0.013” (0.33mm) it impedes the heat transfer between the tube metal and the steam. Thickness of oxide helps to predict tube life. The skin temperature of high temperature components such as super heater and reheater tubes are increased beyond design condition depending on the oxide scale increase in thickness.

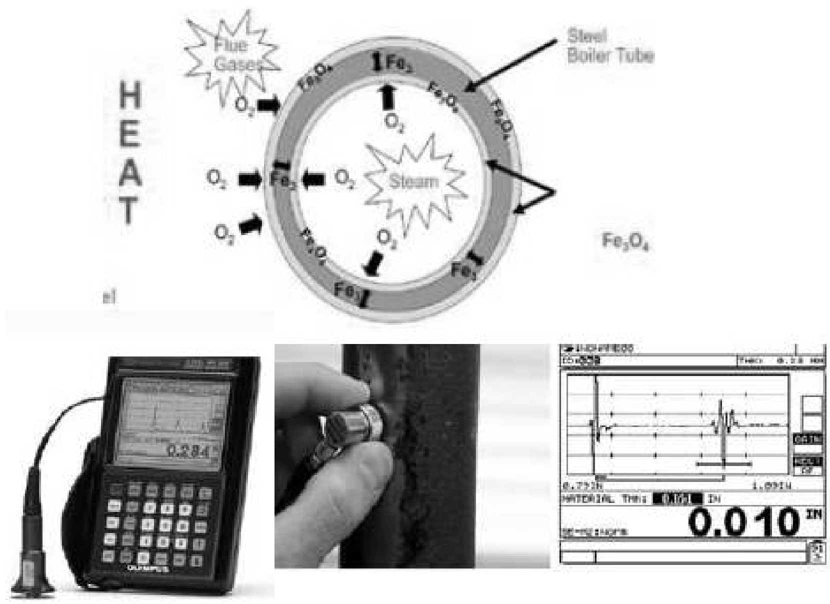


Fig. 9

4.9. In-situ metallography

4.9.1. Microstructure analysis alerts for an indication of metallurgical damages, importantly creep damage**.** The microstructure preparation is time consuming and requires experienced and skilful personnel among all the non-destructive methods employed to estimate the integrity assessment of various components. This technique is of upmost importance since it gives vital information on structural degradation and thus provides early warning for component replacement.

4.9.2. Extensive metallographic methods have been experimented those can correlate for various damage mechani-sms at a go. Replication metallography can reveal cavitation damage, changes in carbide spacing, pearlite spheroidization and dissolution of Bainite. The quantification of microstructural properties through image analysis software helps judgment of creep life expenditure. This method is very useful for condition assessment and residual life assessment study. In-situ Metallography techniques are also developed to take microstructures of the components at the site.

4.9.2.1 Normal and deteriorated microstructure

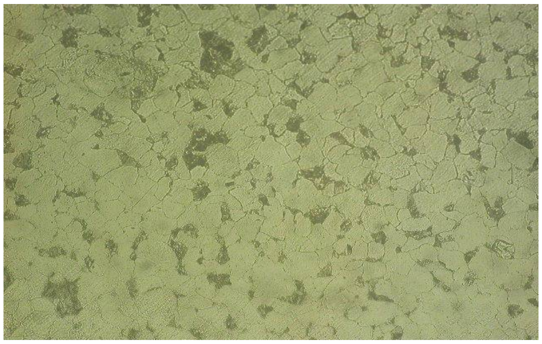


Figure-10(a)

Normal microstructure (good condition tube) which shows a typical ferrite-pearlite structure

Figure-10(b)

Deteriorated microstructure which shows the decomposition of the pearlitic colonies.

4.9.2.2. Isolated cavitation damage is in the Cr-Mo weld after 25 years of service in the power plant. Carbide formation and cavitation damage is observed.

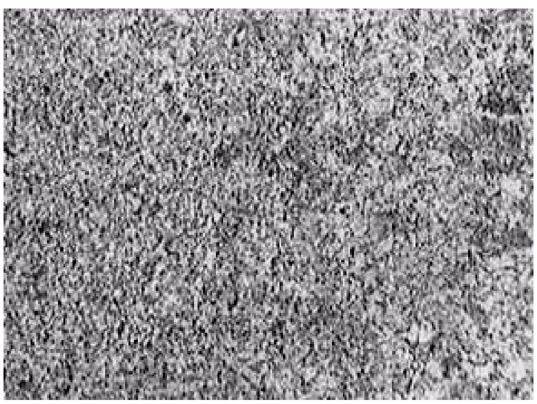


Figure-11(a)

Weld microstructure with isolated creep cavities

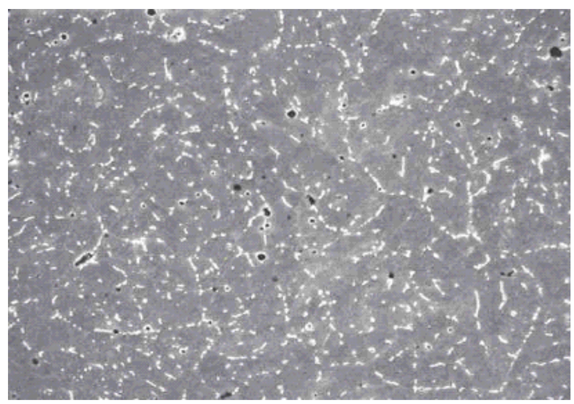


Figure-11(b)

Carbide formation and cavitation on parent material

5. **Remaining Life Assessment Destructive basis**

5.1 The non-destructive testing and evaluation form the basis for life prediction which is mostly more conservative in nature. The actual condition of the components therefore to be validated using laboratory tests. For this purpose, samples to be removed from different locations of the boiler such as superheater, water wall and economizer tubes. A typical creep life assessment is demonstrated as under:

5.2 For remaining life assessment, the tube sample is subjected to visual examination, dimensional measurements, compositional analysis, microstructural rxaminations. room temperature and design temperature tensile test and accelerated creep rupture test.

5.3. The room temperature and design temperature tensile test provide compliance under elastic rupture condition through the measure of yield and ultimate tensile strengths whereas the accelerated creep rupture test provides evaluation for creep strength of the material after service exposure. The accelerated creep rupture test parameters can be set and evaluated for the creep strength of the tube.

6. Conclusions:

6.1 The life assessment approach based on non-destructive and destructive methods enables the management for possible life extension program. The main advantage of life assessment is to build confidence at the same time ensure reliability of the boiler components since prolonged service. If the predicted life of components, for instance the superheater banks, is determined to be higher than envisaged by 2 to 4 years would result in saving of capital investment against early inventory built up. Contrary to this, the other flaws detected during RLA activities may save undue failures by adopting timely repair and rectification. The boiler RLA inspection is more to have consideration as an opportunity rather than compulsion against the statutory requirements.

7. Deliverables of RLA study

6.1 Integration of the various NDT and destructive test results with historical data is an important aspect to make the confident judgement on the residual / extended life of the boiler along with measures required to extend the life of the boiler.

6.1.1. Recommendations on Immediate replacement of component / part is required or it can be replaced after a prescribed period.

6.1.2. Repair of a particular component

6.1.3. Change in steam parameters at the inlet, if required.

6.1.4. Alterations in the mode of future operations aspect

6.1.5. Alterations in the material of certain components

6.1.6. Need for more frequent inspections to monitor the damages.

6.1.7. Deliverables will be on “as is”, “to be” and the design conditions.

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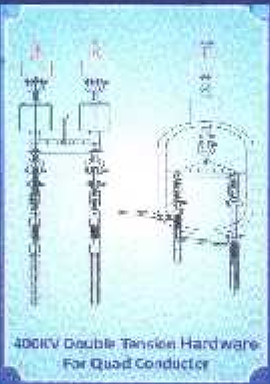

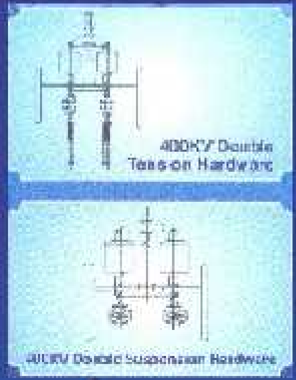

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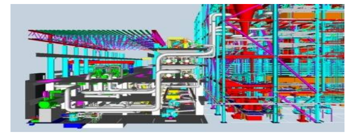
PRESENTATION ON CHALLENGES IN THERMAL POWER PLANT FLEXIBLE OPERATION / CYCLING OPERATION

Rakesh Patil & Rakesh Rathore



FLEXIBLE / CYCLING OPERATION - VULNERABLE LOCATIONS

- Components that are thick and can be sensitive to temperature transient conditions.
- Complex geometry generally has higher local stresses than simple geometry.
- Plant-specific and industry experiences and records—that is, failures, inspection results, and maintenance records—can provide valuable information in determining critical components and vulnerable locations

FLEXIBLE / CYCLING OPERATION-CHALLENGES

- Most of the fossil power plants in operation today were designed and manufactured to be operated under base load conditions.
- Cycling to meet fluctuating demand levels causes unanticipated damages on boiler and plant components.
- Going through the cycle of startup, operation, and shutdown creates higher component stresses that lead to more severe maintenance issues than continuous operation at rated capacity.
- Slow transitions from startup to operation as well as proper cool downs reduce the possibility of premature failures.
- Thus it is a tradeoff between the life cycle cost and commercial operation
- It is important to identify the failures associated with the increased cycling operation to improve the reliability through timely maintenance.

FLEXIBLE / CYCLING OPERATION-VULNERABLE LOCATIONS

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EFFECTIVE DAMAGE MECHANISMS UNDER CYCLING OPERATION

Damage Mechanism	Whether sensitive to cycling operation	Probable area prone for damage due to cycling operation
Creep	Not fully but when coupled with fatigue	Dissimilar metal (having significant difference in their thermal expansion coefficient) weld joints in creep regime i.e. FSH and RH
		Attachment weld in FSH/RH/ PSH (radiation zone)
Thermal Fatigue	Yes, high probability	Header Stub joints/ Attachment weld/ DMW joints/ High Temperature headers/ Critical Piping
Other Damage Mechanisms	Not significantly affected	

FLEXIBLE/ CYCLING OPERATION-VULNERABLE LOCATIONS

A failure study when cycling is considered Component

Component	Total Number of Failures	Percentage of Failures Due to Cycling
Boiler tubes	33	33%
Headers	6	83%
Super-heater tubes	47	19%
Reheater tubes	10	40%
High-pressure heater	17	70%
Low-pressure heater	3	33%

FLEXIBLE / CYCLING OPERATION - THERMAL FATIGUE (MAJOR DAMAGE MECHANISM)

The two key factors affecting thermal fatigue

- The magnitude of the temperature swing and
- The number of cycles

The likelihood of initiating damage And the extent of damage increase with wider temperature swings and an increasing number of cycles.

There is no set limit on temperature swings; however, as a practical rule, cracking is suspected if the temperature swing exceeds about 100°C comparatively faster rate.

Damage is also promoted by

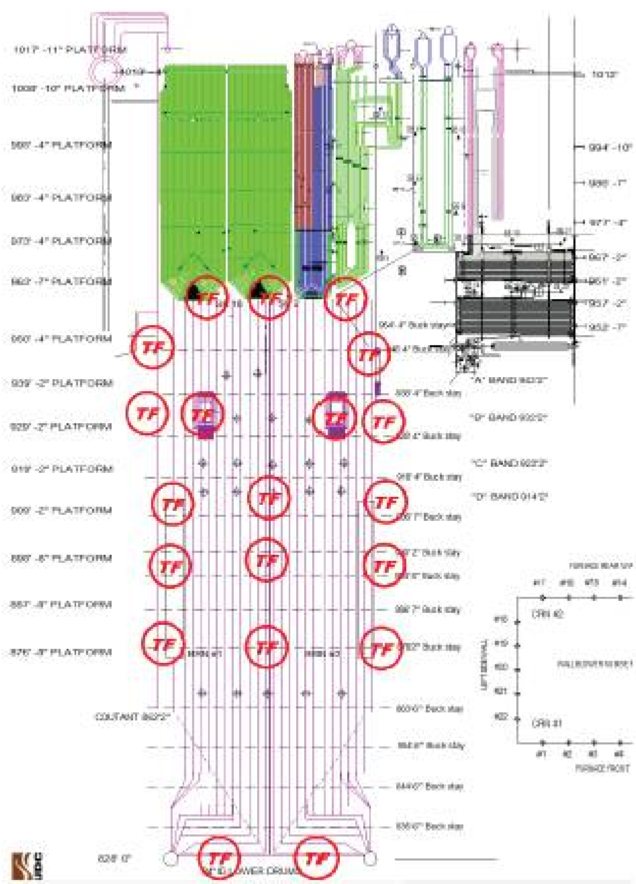
- Rapid changes in surface temperature that result in a varied temperature through the thickness or along the length of a component,
- Rigid attachments,
- Inflexibility to accommodate differential expansion.
- The presence of notches (such as the toe of a weld) and sharp corners (such as the intersection of a nozzle with a vessel shell) and
- Changes in section thickness can serve as initiation sites.

Inspection:

Inspection of this type of damage needs extensive study to detect the early stage of thermal fatigue damage.

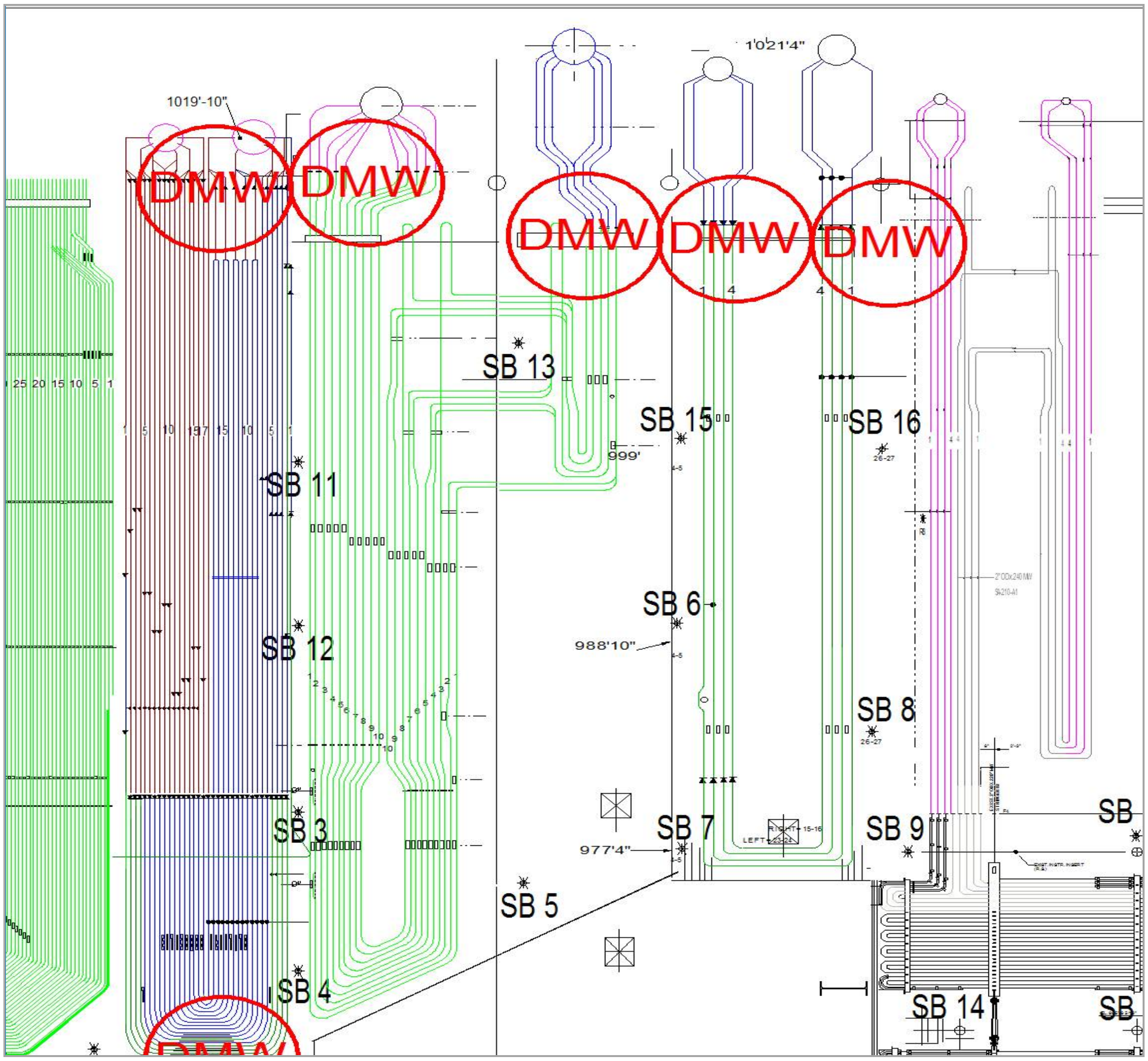
Some of the following tools may be used for early detection:

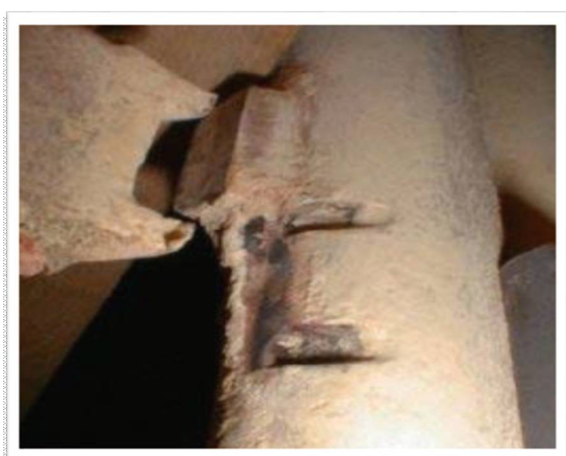
1. Videoscopy for inspection of ligaments in headers
2. Advance Ultrasonic for stub weld / DMW joints etc.
3. WFMPI/ LPT may be adopted to detect from the external surface
   These techniques had limitation for 100% access due to space constrain in headers
4. Eddy Current may be used in place of WFMPI/LPT particularly for header stub inspection



TF = thermal fatigue; BRN = burner; CRN = corner

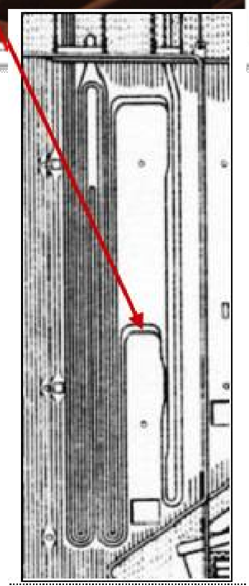
Figure 4-2
Common locations of thermal fatigue in a boiler



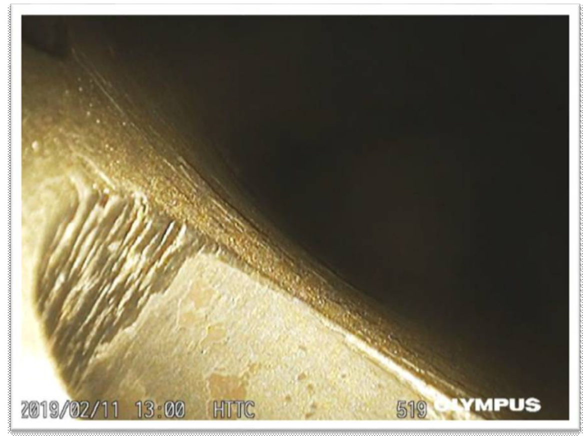


Damage to header stub

Damage to attachment cleats



Damage to DMW joint



Damage to Header ligaments

& Rakesh Rathore

METALLURGICAL PERVIEW AND CASE STUDIES OF EARTHING CONDUCTORS IN POWER SECTOR

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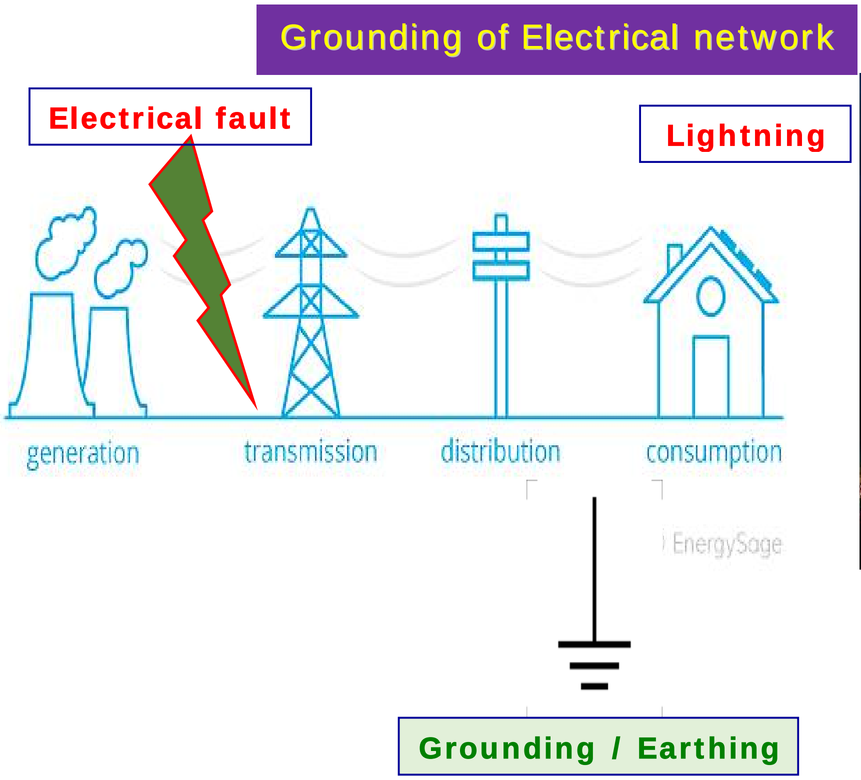


Earthing Concoctors- Types

Traditional Earthing, Which Includes:

- Copper Plates
- Copper Strips
- Copper Wire
- GI Plates, GI Strips & GI Wire
- Salt & Charcoal

Modern Earthing, Which Includes Gel Earthing Electrodes

- Copper Bonded Earthing Electrodes
- Other earthing material i.e.
  - Funnel,
  - Lighting Arrestor,
  - GI Pipe,
  - Nut Bolts etc.

TRADITIONAL GI EARTHING CONDUCTORS

G I Pipes

Lighting Arrestor

Earthing Strips (Hot Dip Galvanized)

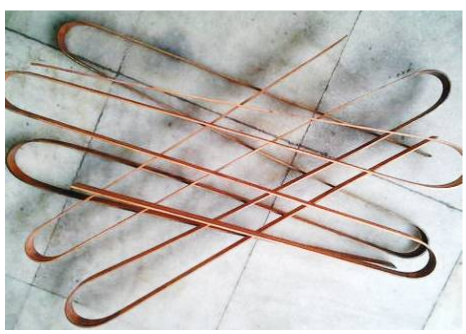
GI Plate (Hot Dip Galvanized)

Earthing Strips (Hot Dip Galvanized)

MODERN EARTHING CONDUCTORS

Copper Bonded Electrodes

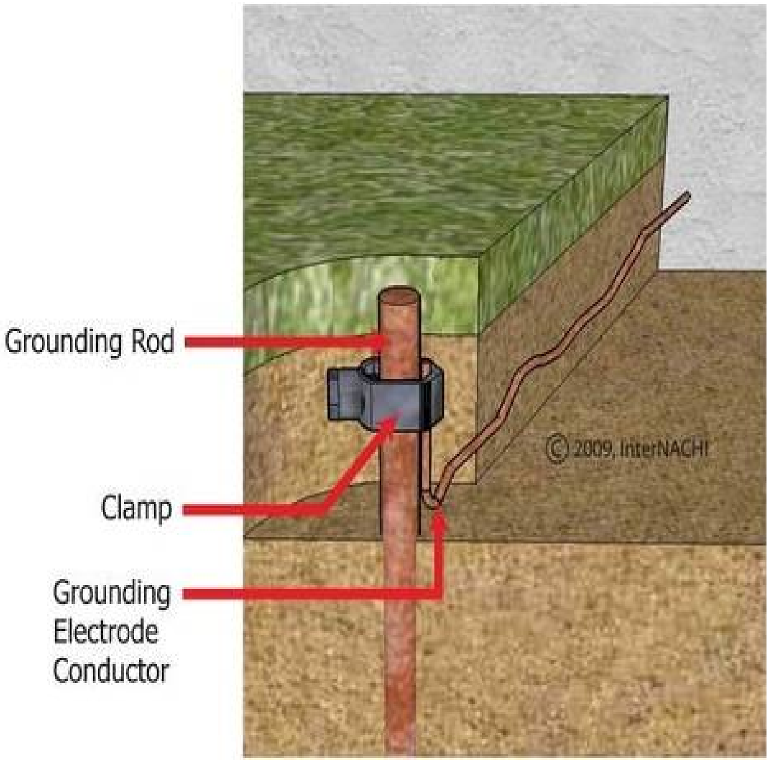
Copper Bonded Strip



Copper Bonded Strip Round

Copper Bonded Earth Strips

Copper Bonded Strip Round Coil



Effecting factors

- rod material
- soil resistivity
- location
- facility type
- size

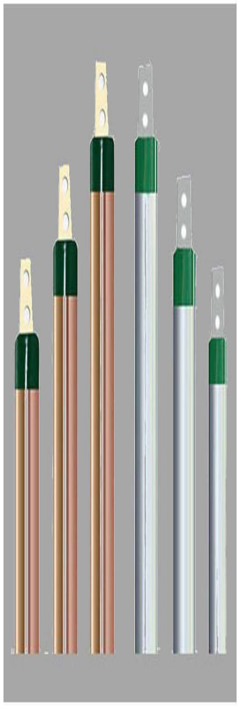
General expected service life of overall grounding system > 40 years

EARTHING CONDUCTOR:
solid copper
copper bonded steel
stainless steel
galvanized steel

SELECTION:
Corrosion resistance
Ease of Driving into the Earth
Theft
Conductivity

IEEE 80 electrical conductivity of different earth electrodes

Material	Conductivity % IACS	Temp. coef. factor	Resistivity at 20^0C µΩ-cm
Copper annealed soft-drawn	100	0.00393	1.72
Copper-bonded steel	40	0.00378	4.4
Copper-clad steel	17	0.00378	10.1
Aluminium-bonded steel	20.3	0.00360	8.48
MS, SAE 1020	10.8	0.00377	15.9
Stainless steel 304	2.4	0.00130	72.0



Conductivity measurement: Case Studies

Material	Sample #	Electrical conductivity % IACS	Dimensions
Copper rod	Sample 1	99.51	25mm
	Sample 2	99.7	25mm
Copper strip	Sample 1	99.95	2.4 x 11.5mm
	Sample 2	99.31	7.7 x 10mm
Copper Zinc strip	Sample 1	23.49	0.4 x 18mm
Aluminium strip	Sample 1	63.24	0.6 x 3.50mm
	Sample 2	50.19	120 x 12mm
	Sample 3	50.11	100 x 10mm
	Sample 4	50.62	50 x 6mm
	Sample 5	50.58	25 x 3mm
	Sample 6	61.1	25 x 1.8mm
	Sample 7	49.4	25 x 1.8mm
Copper clad steel rod	Sample 1	15.47	17.5mm dia
	Sample 2	13.67	14mm + 250 micron Cu
	Sample 3	13.57	17mm + 250 micron Cu
	Sample 4	17.09	17mm + 250 micron Cu
MS Rod SAE 1020	Sample 1	10.68	40mm solid rod
	Sample 2	10.53	40mm solid rod
	Sample 3	8.89	40mm solid rod
	Sample 4	9.61	40mm solid rod
	Sample 5	10.89	40mm solid rod
	Sample 6	10.88	40mm solid rod

METALLURGY OF EARTHING CONDUCTORS

Hard & Soft Copper Conductors

Hard Drawn Copper:

- Difficult to work with stranding & bunching of the finer wires.
- Hard Drawn Copper TS -**3447-4826 MPa** & Conductivity 97 % **IACS.**

Soft Annealed Copper:

- By HT of Cu, Ductility increased to make wire & cable soft & flexible.
- The degree of annealing is controlled by temperature and time.
- Annealed Copper **TS - 2110-2700 MPa** & Conductivity 100.00% **IACS.**

Hard drawn **Cu** has significantly higher **TS** than soft annealed **Cu** and is used as overhead wire whereas the soft annealed **Cu** is flexible and has somewhat improved conductivity over hard drawn **Cu** conductor.

Melting point of 1084ºC

Earthing Conductors – Mechaical Properties

1. Conductivity
2. Tensile Strength
3. Ductility
4. Corrosion Resistance
5. Effect of Alloying on Conductivity / Resistivity:

- Resistivity is increased by any impurity, whether metallic or non-metallic.
- The relationship between resistivity & temperature coefficient of resistivity and impurity content is intricate.
- The alloying increases the mechanical strength of the material and makes it harder.

Earthing Concoctors - Alloying Metallurgy

Alloying Effect on Mechanical Properties:

- Cu: Improves Ductility while increasing Strength & Hardness and Corrosion Resistance as well.
- Al: Al is deoxidizer, slowing grain development and facilitating nitriding.
- Pb: Easy machining.
- Ni: Improves TS. Coefficient of thermal expansion is reduced as CVN increases.
- W: High carbide forming element.
- Si:Enhances magnetic permeability & electrical resistance. Increases the ability to resist oxidation and Assists in the strengthening of ferrite.
- Cr: Strengthens & hardens without compromising ductility & improved wear/corrosion resistance.
- Mn: Promotes steel hardenability.

Difference between Cu-Bonded & Cu-Clad Steel

Primary difference:

Manufacturing processes which way the copper is composited on the steel core.

Cu-Bonded Steel:

- It is manufactured through a continuous electro-plating process of Cu over steel core, resulting in a permanent molecular bond between the two materials.
- The copper layer thickness is measured in unit of (mils).

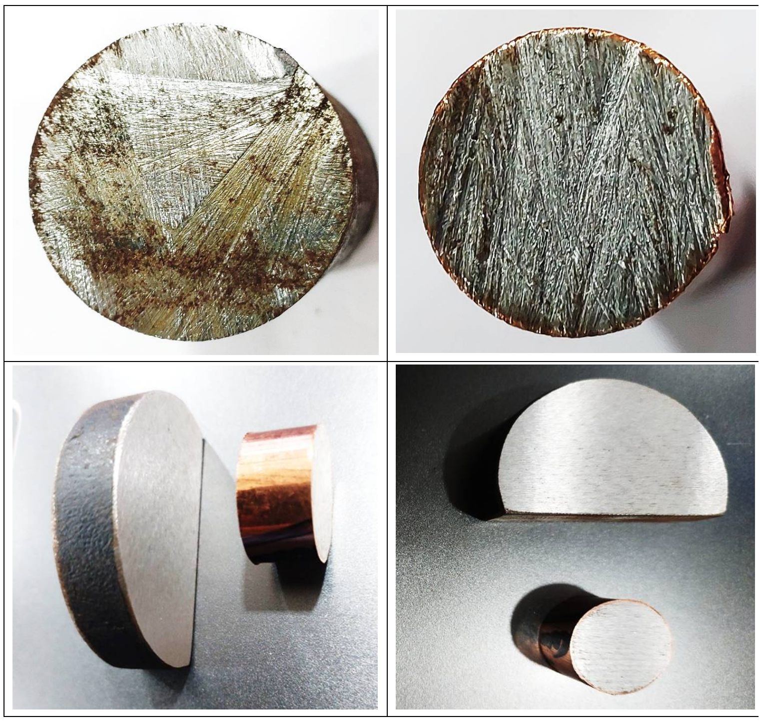
Cu-Clad Steel:

- It is manufactured by installing two copper strips over a steel core using pressure & heat to form a metallurgical bond.
- Cu-layer thickness is adjusted to the percentage conductivity of pure copper.

- Cu-layer thickness is adjusted to the percentage conductivity of pure copper.

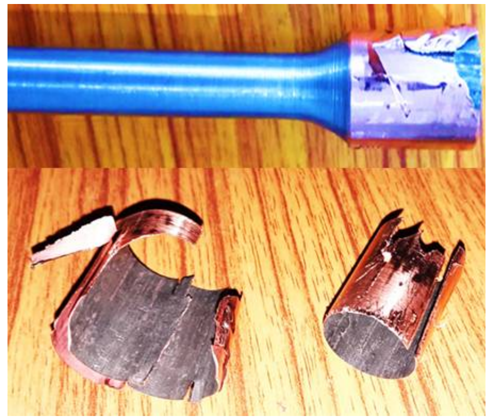
- Most common conductors used in the US are 40% conductivity of copper

Earthing Conductors– Grade Identification



Earthing Conductors – Chemical Analysis

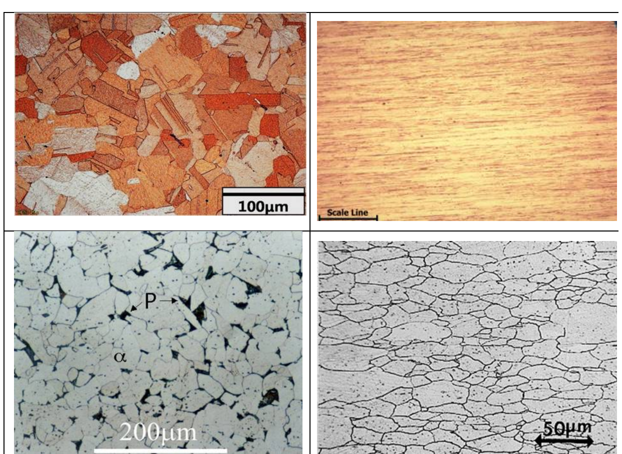
Earthing Conductors



Earthing Conductors – Grade Identification

Element	Mild Steel	Mild Steel with Cu cladded
C	0.18	0.24
Si	0.19	0.13
Mn	0.62	0.42
P	0.029	0.026
S	0.047	0.038
Cr	0.02	0.19
Mo	0.003	0.01
Ni	0.02	0.04
Al	0.003	0.003
Cu	0.067	0.12
Hardness observed	126 BHN / 69 RB	228BHN / 96 RB

Earthing Conductors– Microstructure



Microstructure of Cu & Steel, a) Annealed Cu (700 °C/ 99.99%), b) Wire (Cu 99.8, Cd 0.7-1.2, Fe 0.02) c) L-Carbon Steel (≤0.3% C) - Ferrite & Pearlite d) Rolled Stee

Earthing Conductors– Microstructure of MS Rod

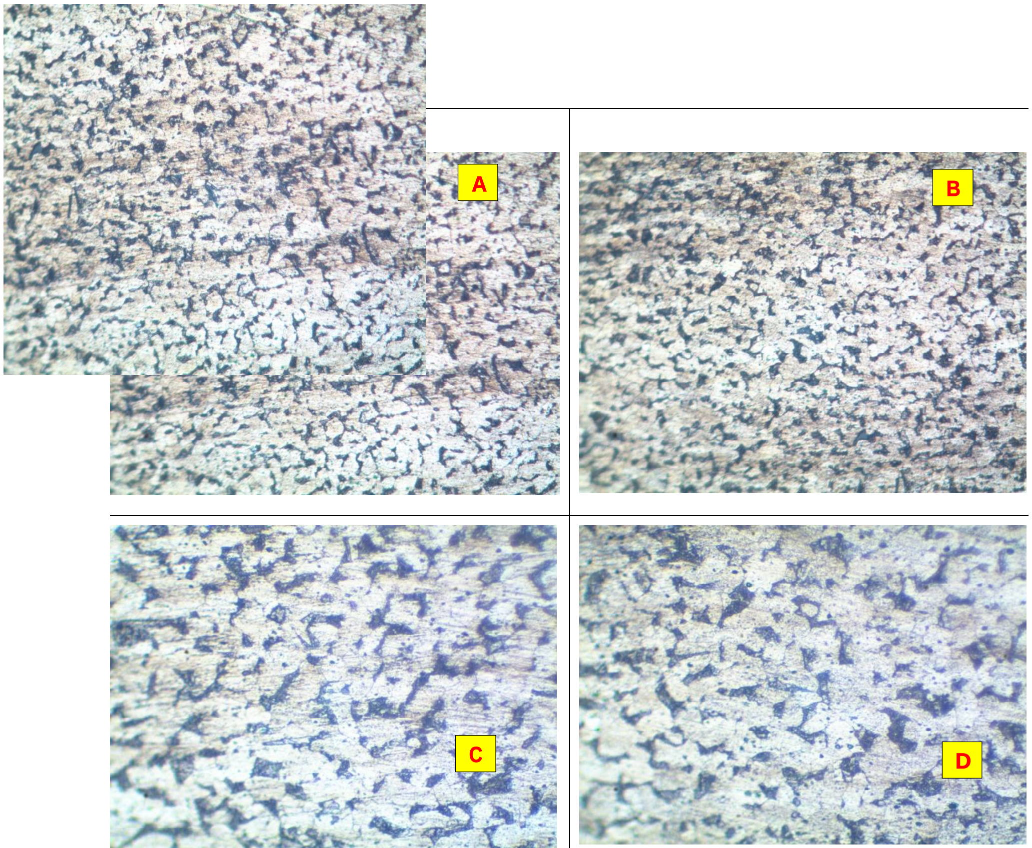


Fig.4: Mild Steel rod Microstructure (a-b) Mg x40, e) Mgx 100 & (f) Mgx 200 shows Ferrite & Pearlite.

Earthing Conductors– Microstructure of Cu-Cladded

Fig.6: Cu-Cladded Microstructure (a-d) Mg x40, (e) TMT Str & (f) TS sample.

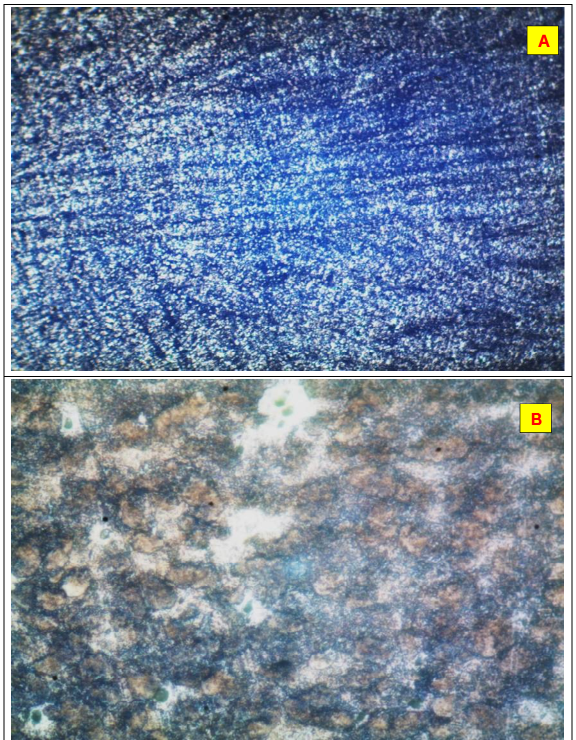


Fig.7: Cu-Cladded Microstructure (a) Mg x40, (b) Mgx 400

Conclusions:

1. Conductivity of pure copper in both form either in rod or strip form found for > 99 % IACS.
2. Conductivity of Al-Strip electrode observed 50% IACS against the general requirement of 61 % IACS.
3. Conductivity of Cu-Cladded observed 13-17 % IACS.
4. Conductivity of MS steel rod observed 8.89-10.89% IACS.

MS Rod Of SAE 1020 Grade:

- Surface corrosion observed within 2 days of monsoon atmospheric condition and After wiping out surface corrosion with emery paper, improvement in % IACS observed.
- Chemical analysis of MS steel rod shows C-0.18%/Mn-0.62% & Si-0.19%.
- Hardness observed 69RB / 126 BHN.
- Microstructure shows normalized ferrite and pearlite structure.

Copper Clad Steel Rod:

- For Copper clad steel rod, delayering of cladded copper during tensile test observed i.e., Copper sleeve come out before reaching to permanent deformation or fracture of the rod.
- Chemical analysis shows C-0.24%/Mn-0.42% & Si-0.13%,
- Hardness observed 96RB / 228 BHN.
- Microstructure shows thermo-mechanical rolled structure.
- Core side microstructure is showing ferrite & pearlite and periphery showing martensite whereas between core and periphery microstructure is bainite.

POWER PLANT CORROSION (CONSEQUENCES & PREVENTION)

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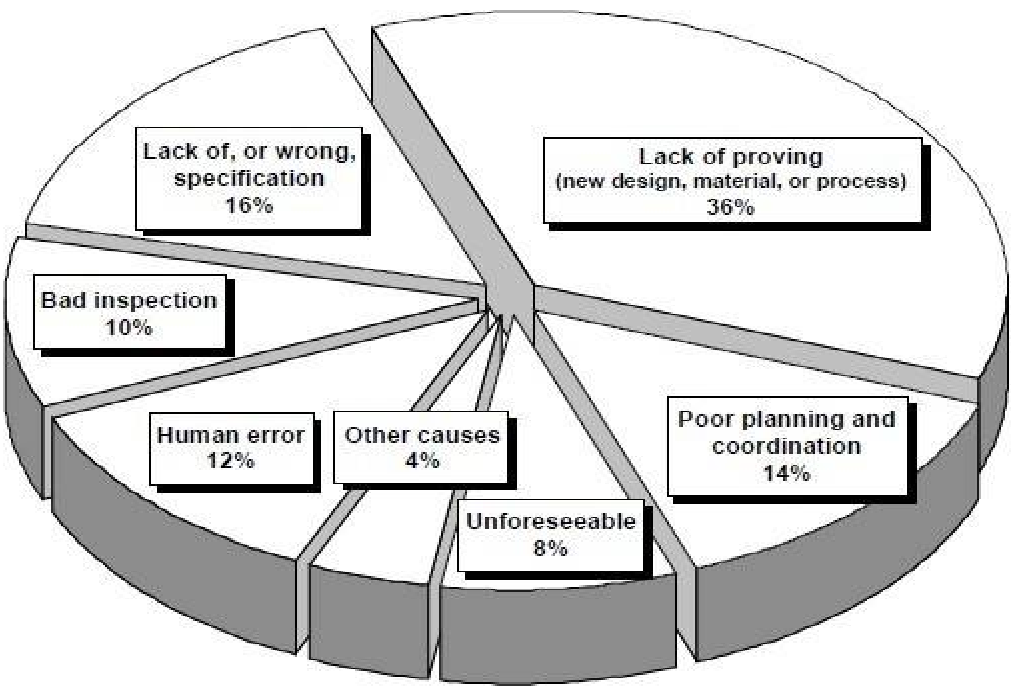
Professor, Emeritus & Director, ITMU & Dean
ITM (SLS) Baroda University, Vadodara

Introduction to Power Plant Corrosion:

Corrosion in power plants leads to costly repairs, prolonged maintenance, material losses, poor performance, and if left untreated, failure.

Corrosion prevention in the form of preventive and control strategies, such as regular inspections and the use of protective coatings is very necessary. The success of these coatings, however, depends on creating the optimal conditions to clean the respective surface and allow coatings to dry according to the manufacturer's instructions.



Pie chart attribution of responsibility for corrosion failures investigated by a large chemical company

What are the Consequences if you forego the Corrosion Prevention in a Power Plant?

- **Safety risks:** When corrosion affects systems carrying steam or hot water—such as pipes—material or welds may fail, causing bodily injury or death.
- **Fouling:** Power plant systems foul because of the ingress of moisture, dust, or salt in the air.
- **Pipe corrosion:** Insulating with an outer finish or jacketing keeps water from contacting tank shells or pipes, preventing corrosion, pitting, cracking, and failure.
- **Contract-related fines:** When corrosion affects a plant's system, it may not start up after a maintenance outage, leading to non-delivery fees for being out of service
- **Pollution control**: Corrosion in tanks may hinder a plant's attempts to control sulfur emissions in the environment. Sulfur emissions lead to acid rain, which damages buildings and other structures in a power plant.
- **Boiler tube problems**: Water, steel, and dissolved oxygen within boiler units causes boiler tubes to oxidize and corrode. The corrosion forms grooves within the tubes that lead to cracks and boiler failures.
- **High maintenance costs**: Corrosion can account for up to 75% of a plant's arrest time during maintenance and up to 54% of production costs.
- **Gas or air leaks:** Unaddressed plate corrosion leads to air or gas leaks. The problem gene-rally occurs when the lagging system fails.
- **Flue gas inlet duct problems**: Gases within ducts attack the system physically and chemically.
- **Scrubber outlet duct moi-sture:** Outlet ducts gene-rally have a lower temperature than inlet ducts, making them more susceptible to conden-sation.
- **Flue liner failures:** Freestanding stacks without windshields or protective liners suffer thermal shock and chemical attacks.
- **Low-temperature hot-corro-sion in gas turbines**: Transient metal oxides react with sodium sulfate, forming eutectic salts that prevent the formation of protective alumina or chromia.

<u>Power Plant Corrosion: Danger Zones</u>

- Hot and cold piping systems
- Turbines
- Boilers
- Reactors
- Towers
- Nacelles
- Plates
- Boiler tubes
- Welding seams
- Flue inlet gas ducts
- Bypass ducts

- ➢ Scrubber outlet ducts and modules
- ➢ Stacks
- ➢ Areas containing de-minerali-zed water
- ➢ Stack liners
- ➢ Fuel handling areas
- ➢ Collection sumps

<u>What is corrosion?</u>

- Destruction of metal or deterioration of the properties of material due to the chemical or electrochemical reaction with its surrounding environment.

- Loss due to corrosion accounts for more failures in terms of cost and tonnage than any other environment
- Losses incurred in India annually is Rs. 1.52 lakh crore **(2-4 % of the GNP).**

Electrochemical Corrosion

Oxidation Reaction (Free electrons):

M→ M+n +ne- (From metal to its ion)

i.e.: $Fe \rightarrow Fe2^{+} + 2e^{-}$

$Al \rightarrow Al3^{+} + 3e^{-}$

>>>Produces Electrons

<u>Reduction Reactions (Consume electrons)</u>

Hydrogen Evolution:

$2H^{+} + 2e^{-} \rightarrow H_2$

Oxygen Reduction (acid):

$O_2 + 4H^{+} + 4e^{-} \rightarrow 2H_20$

Oxygen Reduction (neutral or basic): $O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$

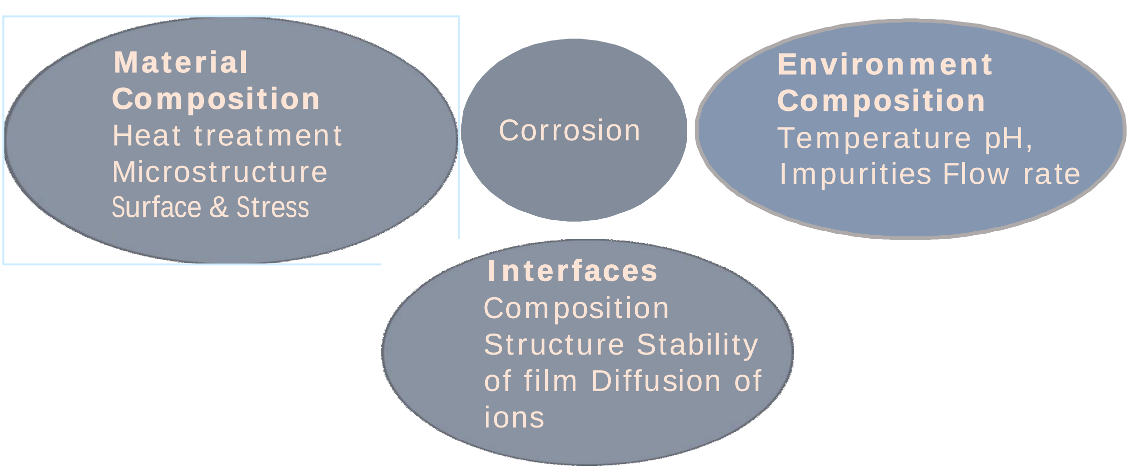
Metal Ion Reduction:

$M^{3+} + e^{-} \rightarrow M^{2+}$

Metal Deposition:

$M^{+} + e^{-} \rightarrow M$

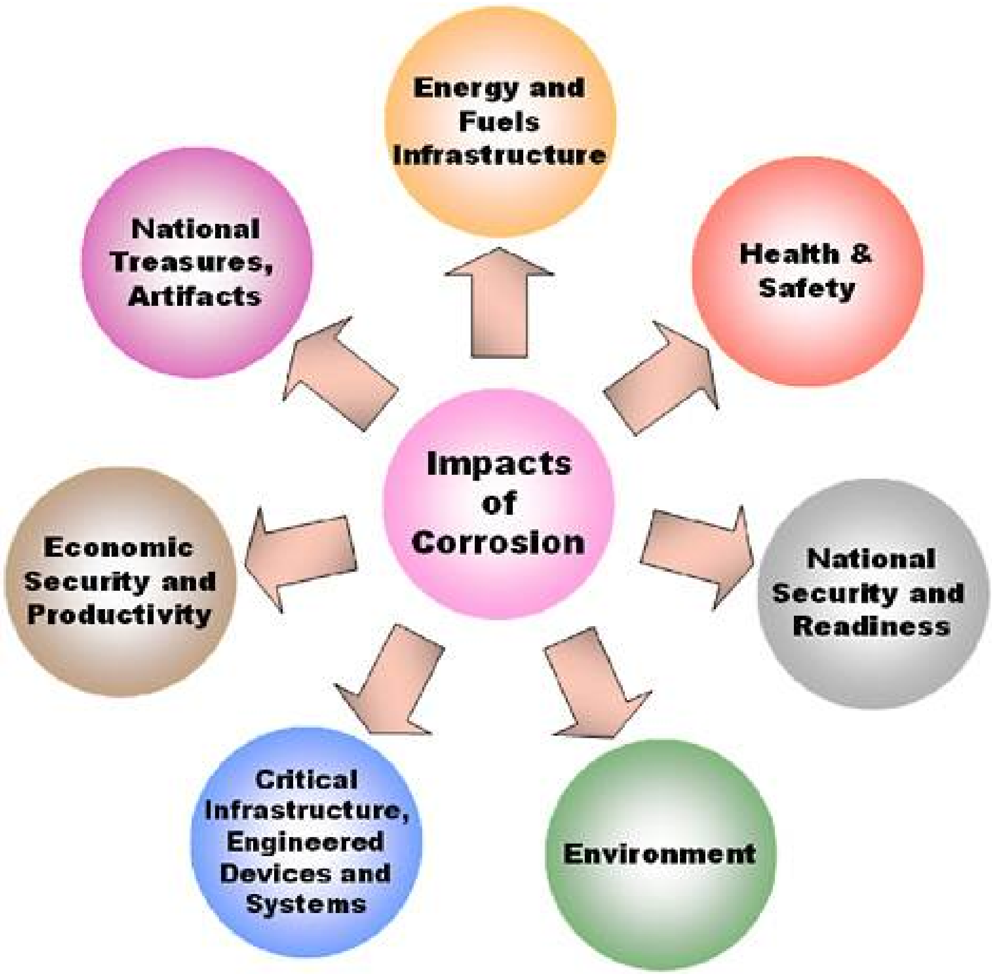
<u>"Corrosion knows no national boundaries"</u>



CORROSION IS INTERDISCI-PLINARY IN NATURE

Synergistic influence various parameters of material, enviro-nment of and their interfaces play a key role in the failure of com-ponents due to corrosion.

IMPACTS OF CORROSION

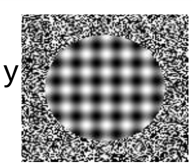


Corrosion Manifestation Category

Corrosion can be divided into three categories

Group I: Those, which can usually be distinguished by the naked eyes

Group II: Those, which are more readily recognised with the assistance of supple-mentary means of examination.



Group III: Those, which usually should be verified by microscopy of one kind or another (optical, scanning, electron etc.).

Types of Common corrosion in Power Plants

- General / Uniform corrosion / Oxidation Corrosion
- Galvanic corrosion

- Crevice corrosion
- Pitting corrosion
- Intergranular corrosion
- Erosion corrosion
- Stress corrosion

General corrosion

- Uniform thinning without appreciable localized attack.
- Types of uniform corrosion:
  - o Atmospheric corrosion
  - o Molten salt corrosion
  - o High-temperature corrosion
  - o Oxidation
  - o Corrosion in liquid metals

A. Oxidation (Oxide Corrosion)

Oxidation is the process in which a metal alters its properties properties to become more stable in an environment. It occurs in the presence of oxygen or moisture, or both. Salts, high temperatures, and acids can accelerate oxidation.

Hot, or dry, corrosion is a type of oxidation that occurs in the absence of moisture when a surface has a thin film of salt in an oxidizing gas coating it. This type of corrosion affects gas turbines, incinerators, boilers, and internal combustion engines.

This type of corrosion occurs when lagging isn't installed properly, or when protective surface coatings fail or were never applied.

Control of Uniform Corrosion

Uniform corrosion can be slowed or stopped by using the following SEVEN basic facts.

1. Slow down or stop the movement of electrons

Coat the surface with a non-conducting medium such as paint, lacquer or oil.

Reduce the conductivity of the solution in contact with the metal an extreme case being to keep it dry. Wash away conductive pollutants regularly.

2. Apply a current to the material. (Cathodic Protection)

3. Slow down or stop oxygen from reaching the surface. Difficult to do completely but coating can help.

4. Prevent the metal from giving up electrons by using a more corrosion resistant metal higher in the electrochemical series.

- Use a sacrificial coating, which gives up its electrons more easily than metal being protected.
- Apply cathodic protection.
- Use inhibitors.

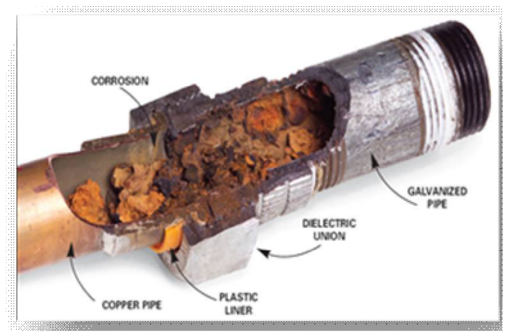
5. Select a metal that forms an oxide that is protective and stops the reaction

6. Use thicker materials for corrosion allow

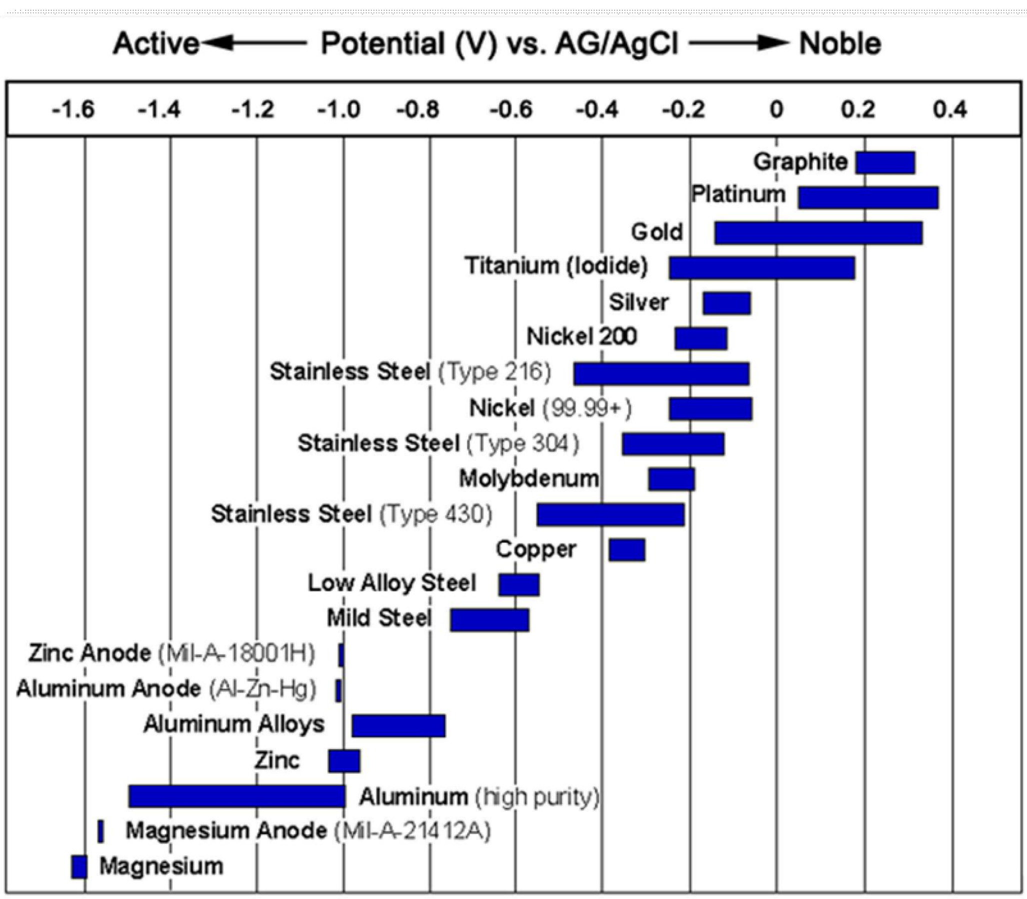
7. Control and consideration of environment.

Galvanic Corrosion

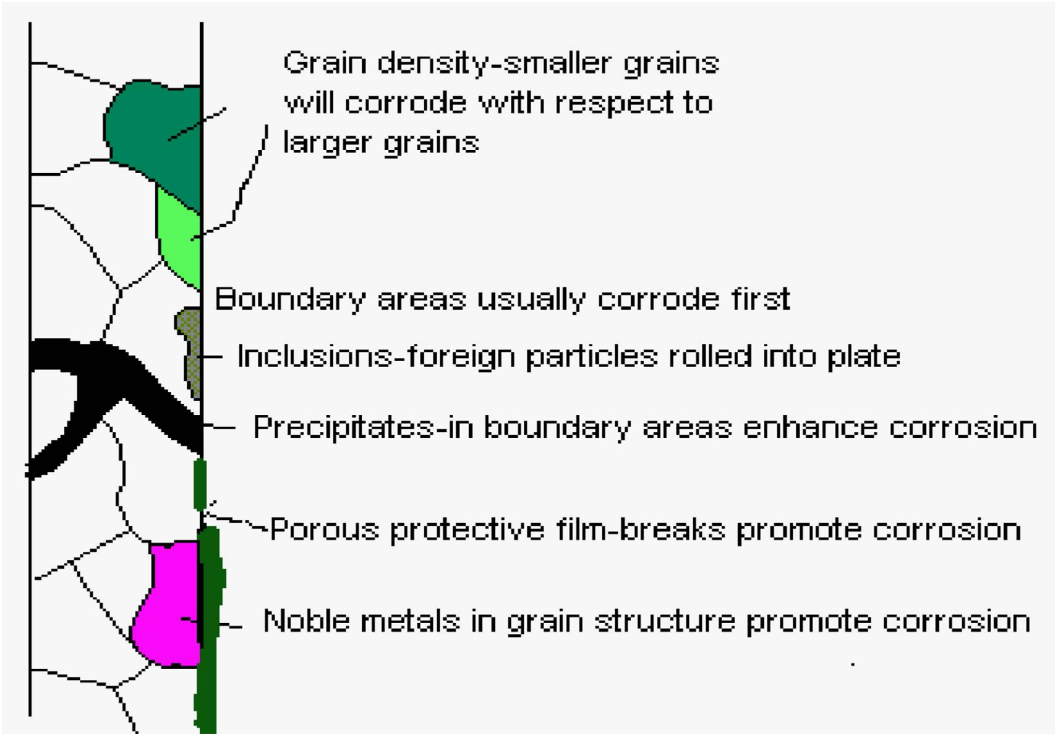
- Dissimilar metals or alloys are electrically coupled in a common electrolyte
- corrosion of the less corrosion resistant metal increases(ano-anodic)
- corrosion of the more corrosion resistant metal decreases (cathodic)
- The driving force = potential developed between the dissimilar metals
- Factors affecting the extent of galvanic coupling.
  - potential difference between the metals or alloys
  - nature of the environment
  - polarization behavior of the metals or alloys
  - geometric relationship of the
  - component metals or alloys



Galvanic series



Galvanic Action Within Metal



B. Galvanic Corrosion

Galvanic corrosion occurs when there are two dissimilar metals or alloys in an electrolyte contact each other, creating an electrical reaction that promotes corrosion.

In a plant, for example, a humid area with steel pipes and copper fittings could experience this type of corrosion, as one metal would become an anode and the other a cathode, accelerating oxidation.

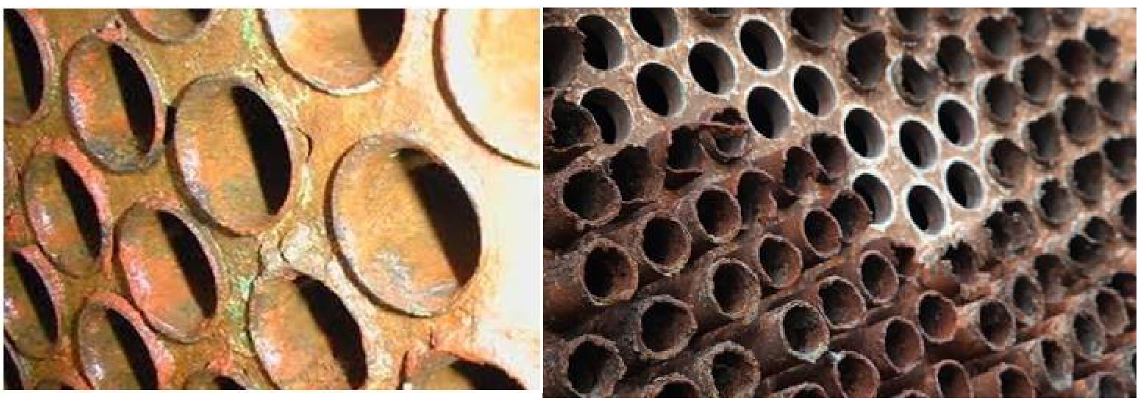


Fig. Boiler Tube Galvanic Corrosion

Control of Thermo-Galvanic Corrosion

- Avoid uneven heating, cooling and formation of hot spots.
  - Design layout to prevent adverse effect of one component on the other.
  - Provide for continuity of insulation or lining.
  - Prevent by design access of differentially heated or cooled liquids from exterior sources

De-alloying

Group II

Those, which are more readily recognized with the assistance of supplementary means of examination.

It results from the fact that the components of the alloy corrode at different rates.

Identification

1. De-alloying is normally detectable as a colour change.
2. Brasses will turn from yellow to red
3. Cast iron from silvery gray to dark gray.
4. Gray iron that has suffered graphitic corrosion can be cut with a penknife.

Combination of Alloys and the Environment Subject to De-alloying and Elements Preferentially Removed

Alloy	Environment	Element removed
Brasses	Many waters, especially under stagnant condition	Zinc (dezicification)
Grey Iron	Soils, Many waters	Iron (Graphite corrosion
Aluminium Bronzes	Acid containing chloride ions	Aluminium
Silicon Bronzes	High temperature steam and acidic species	Silicon (desiliconification)
Tin Bronzes	Hot brine or steam	Tin (destannification
Copper Nickels	Copper nickels	Copper nickels

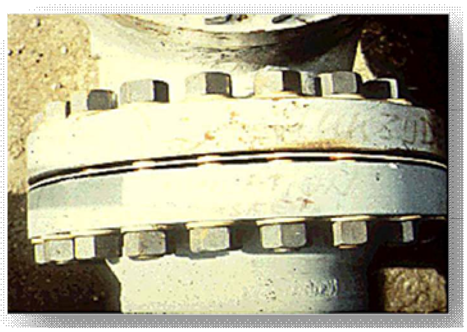
Control – De-alloying

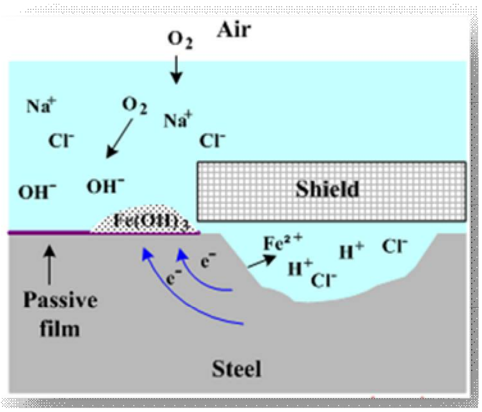
- Coating the material
- Reducing the aggressiveness of the environment Use of cathodic protection
- Select metals/alloys that are more resistant to de-alloying.

e.g., Inhibited brass is more resistant to dezincification that alpha brass

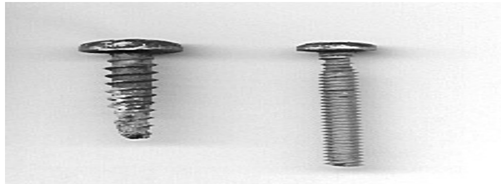
Ductile iron is more resistant to graphitic corrosion than gray cast iron.

Crevice corrosion





Crevice Corrosion on Screws



Exposed to water both under the head, and on the inside of the hull, where it has thinned at both locations.

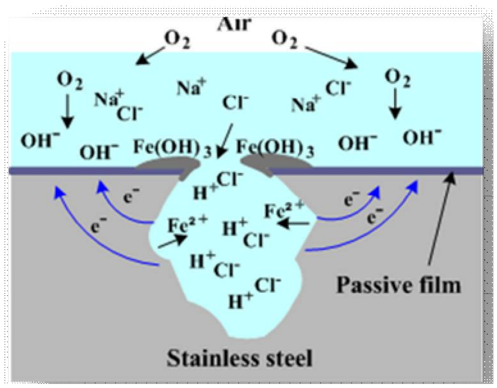
The typical wasting of the shank right under the screw head.

Control of Crevice Corrosion

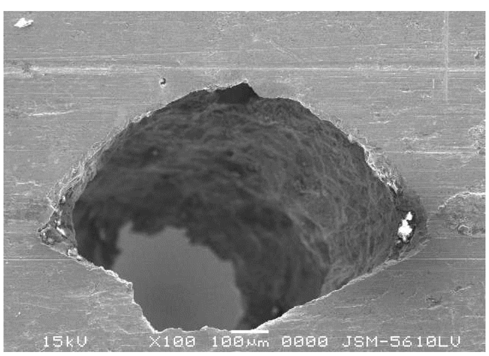
- Close crevices in existing lap joints by continuous welding, caulking, or soldering.
- Use welded butt joints instead of riveted joints in new equipment. Sound welds and complete penetration are necessary to avoid porosity and crevices on the inside (if welded from one side)
- Design vessels for complete drainage; avoid sharp corners and stagnant areas. Complete draining facilitates washing and cleaning, tends to prevent solids from settling on the bottom of the vessel.
- Inspect equipment and remove deposits frequently.
- Remove solids in suspension early in the process or plant flaw sheet, if possible….
- Break the electrical contact using plastic insulators or coating between the metals.
- Prevent ion movement by coating the junction with an impermeable material, or ensure environment is dry and liquids cannot trap

- Select metals/alloys as close together as possible in the galvanic series
- Avoid unfavorable area effect of a small anode and large cathode.
- Avoid threaded joints for materials far apart in the galvanic series.
- Design the anode part for occasional easy replacement.

Pitting Corrosion



Chloride attack on stainless steel



SEM Image of Pitting Corrosion

Manifestation of Pits

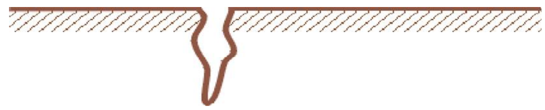
<u>Sideway Pits</u>

Subsurface

Undercutting

Horizontal grain attack

<u>Through Pits</u>



Narrow, deep

Elliptical

Vertical grain attack

Elliptical

- There are several ways by which pits can be evaluated including pit size and density measurements
- The most commonly used parameter is "Pitting Factor", Deepest metal penetration
- Average metal penetration of the total pits at the surface
- 1 Pitting Factor represents uniform corrosion. The larger the number, greater the depth of penetration.

Effect of Certain Parameters on Initiation to pit

- **Velocity**
  Velocity or increasing velocity often decreases pitting effect.
- Metallurgical variables, Mechanical & Surface condition variables.

Effect of Alloying on Pitting Resistance of Stainless Steel Alloys

Element	Effect of pitting resistance
Chromium	Increases
Nickel	Increases
Molybdenum	Increases
Silicon	Decreases Increases when present with molybdenum
Titanium and Columbium	Decreases resistance in $FeCl_3$ other mediums no effect
Sulphur & Selenium	Decreases
Carbon	Decreases especially in sensitised condition
Nitrogen	Increases

C. Pitting Corrosion

Pitting corrosion is a localized form of corrosion by which cavities or "holes" are produced in the material. Pitting is considered to be more dangerous than uniform corrosion damage because it is more difficult to detect, predict and design against. Corrosion products often cover the pits.

It gives generally leakage in Boilers and Pipe Lines.

Control Over Pitting Corrosion

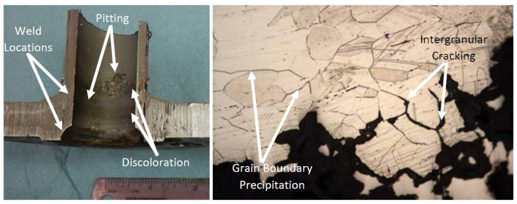
1. Selecting a resistant material.
2. Ensuring a high enough flow velocity of fluids in contact with the material or frequent washing.
3. Control of the chemistry of the fluids and use of inhibitors.
4. Use of protective coating
5. Maintain the material's own protective film

Pits can be track initiators in stressed components or those with residual stresses resulting from forming operations. This can lead to Stress Corrosion Cracking.

D. Intergranular corrosion

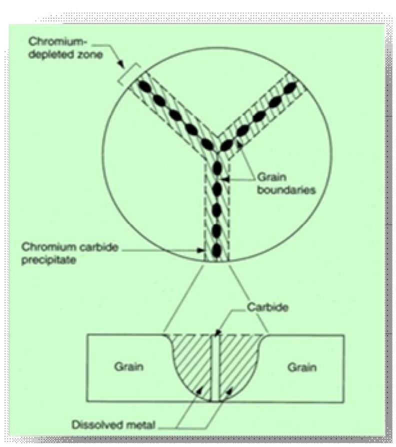
Intergranular corrosion can be defined as localized corrosion at and adjacent to grain boundaries, with relatively little corrosion at the grains.

Intergranular corrosion occurs when certain metals and alloys reach temperatures between 425°C and 870°C (887°F to 1598°F.) These temperatures are most common during welding, heat treatment, or operation in high-temperature environments, especially during the welding process.



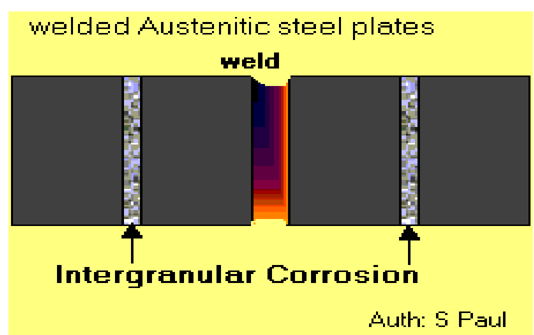
Intergranular Corrosion (IGC)

- Localized attack at and adjacent to grain boundaries, with relatively little corrosion of the grains.
- Alloy sensitive to IGC, disintergrates and / or loses its strength when exposed to environments
- **Causes of intergranular corrosion**
  - Segregation of impurities at the grain boundary Fe in Al alloys.
  - Enrichment of one of the alloying elements
  - Depletion of one of these elements in the grain boundary areas.



Intergranular Corrosion

- Grain boundary is normally slightly more reactive than grain body, but sometimes reactive elements segregate at the grain boundary, giving rise to Intergranular corrosion.
- When stainless is heated in the temperature range of 425° to 815°C, Cr, the passivating element in the steel, migrates from the grain body to the grain boundary with precipitation of chromium carbide $Cr_{23}C_6$.
- As a result grain boundary or adjacent regions become less corrosion resistant, causing preferential corrosion at grain boundary, leading to detachment of grains out of the surface.
- When two stainless steels plates are welded, regions away from welding zone may get heated up in the above mentioned temperature range, leading to Intergranular Corrosion



Intergranular Corrosion of stainless steels and nickel based alloys

Exposure temperature = 425^0 to 815^0 C

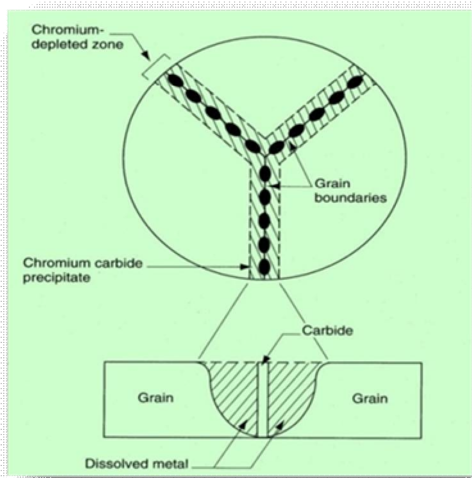
↓

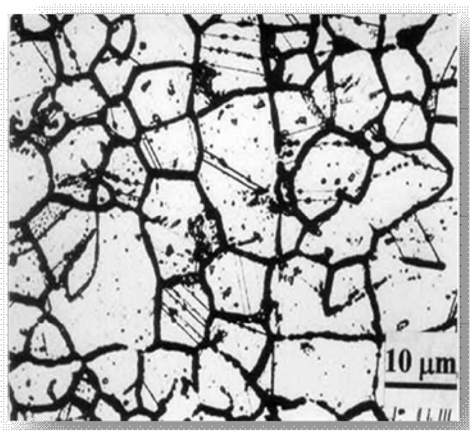
Sensitization

↓

Preferential attack of Cr - depleted zone

Precipitation of $Cr_{23}C_6$ at grain boundary





Stress Corrosion Cracking

- **Cracking process that requires the simultaneous action of a corrosive and a sustained tensile stress.**
- **Requirements**
  1. Steel susceptible to SCC
  2. Corrosive environment
  3. Tensile stress or residual stress
- **Stages of SCC**
  1. Generation of environment
  2. Initiation of SCC
  3. Propagation of SCC

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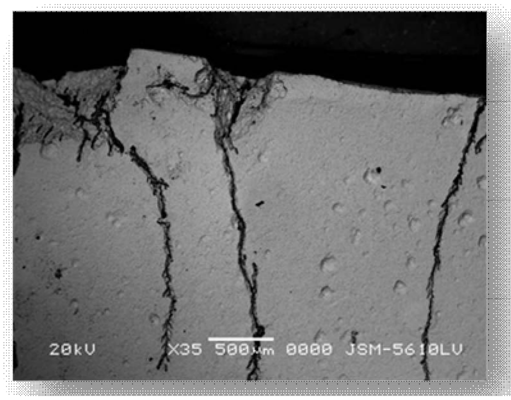
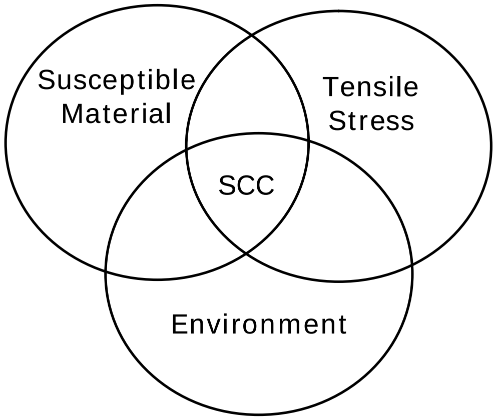


Stress Corrosion Cracking

Unfortunate Facts of SCC

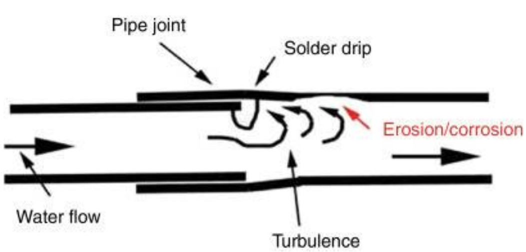
- Cracking takes place in otherwise best alloys
- Passive alloys resistant to general corrosion
- High strength steels prone to cracking
- Cracking at RT



Material	Environment
Austenitic SS (annealed)	Cl^-, OH^-, HTHP Water
Austenitic SS (sensitized)	HTHP Water, dilute Cl^-, OH^-, F^-, Polythionic acid
Carbon & Low Alloy Steel	OH^-, NO_3^-, CO_3^- & HCO_3^- solutions, anhydrous NH_3
High Strength Low Alloy Steel	Water, moist air, Cl^- & $Cl^{- -}$, H_2S
Ti alloys	Red fuming HNO_3, hot molten salts, methanol, salt water

E. Erosion Corrosion

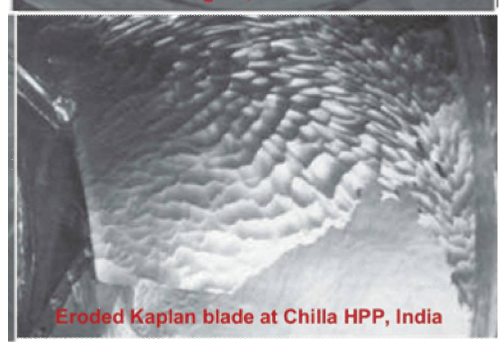
Erosion is a type of corrosion that occurs when high fluid surface velocities are exposed to aggressive chemical environments. In this the combination of high fluid surface velocities and an aggressive chemical environment that wears away a surface's protective scale or coating.

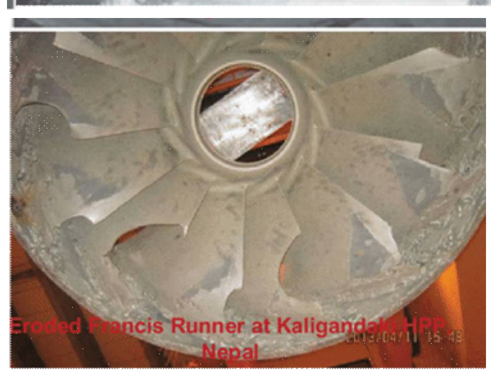


The reaction wears away a metal object's protective scale or causes a surface coating to fail. As the surface erodes, it begins to thin.

Erosion is a serious problem within turbines, pipelines, valves, heat exchanger tubes, and combustion systems. It is one of the main causes of downtime in power plants, accounting for up to 75% of the total arrest time. Sometimes the cost of replacing broken tubes can make up over 50 percent of the total production costs.

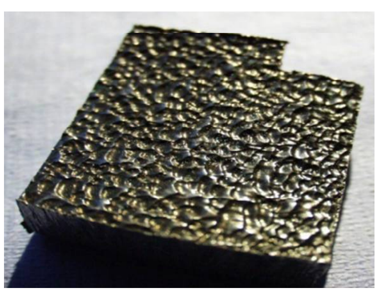

Eroded Francis Runner at Maneri Bhali HPP, Stage-II, India


Eroded Kaplan blade at Chilla HPP, India


Eroded Francis Runner at Kaligandaki HPP, Nepal

Erosion-Corrosion: Cavitation: Fretting

- Erosion-corrosion is attack accelerated by high velocity flow, either washing away protective films or mechanically disturbing the metal itself. The true nature of the attack, may require supplementary micro-scopy, despite the characte-ristic flow pattern visible to the naked eyes
- Surface damage by Erosion, Cavitation or Fretting is often difficult to identify. There are features of each Damage Mode that make them subject to confusion.
- The differences in methods for alleviating the severity of damage, it is important that the mode of damage be correctly identified in the failure analysis.
- **Erosion-corrosion and Cavi-tation are associated with flowing fluids.**



Erosion -corrosion

Erosion-Corrosion

Cavitation

Cavitation

- **Fretting associated with surface contact and small relative motions between the two contacting surfaces.**

Fretting

Fretting

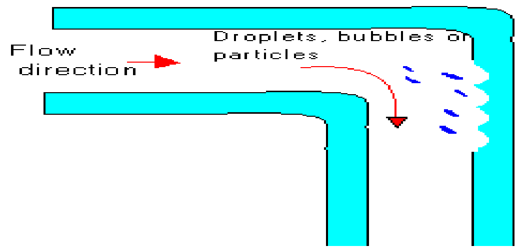
- ➢ Erosion-corrosion is caused by the relative movement between a corrosive medium and metal surface
- ➢ Friction and wear leads to formation of grooves, valleys, wavy surfaces, holes, etc., with a characteristic appearance (comet tails, horseshoe marks, etc.).
- ➢ Soft metals and alloys (e.g. copper, lead etc.) or those whose corrosion resistance depends on the surface film (aluminium, stainless steels).

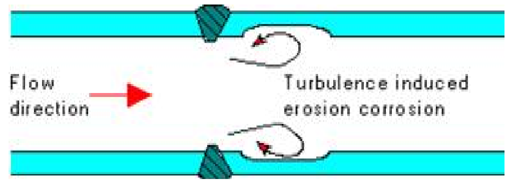
Means of limiting erosion-corrosion:

- Choose a more resistant material
- Improve the plant design
- Adjust the medium (control oxygen content, lower the temperature, use inhibitors, filter out solid particles)

•

Erosion-Corrosion Damage in pipe line



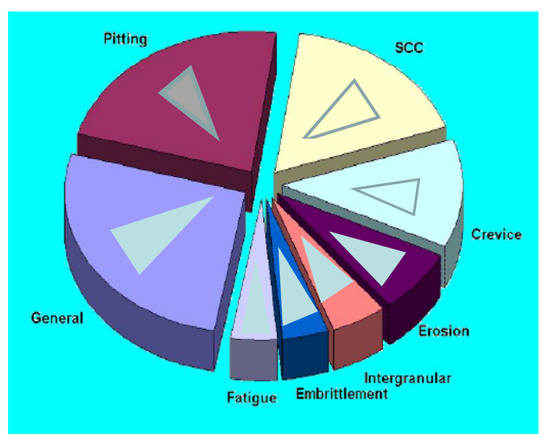


Erosion-Corrosion Damage in pipe line

Erosion – Corrosion Control

Five methods of prevention or minimization of damage due to erosion corrosion are used.

- In order of importance or extent of use,
- Better materials
- Design
- Alteration of the environment
- Coatings
  - Cathodic protection.



Pie Chart **summary of 363 failure cases investigated in industries**

CONCLUSION

- Corrosion in Power plant cannot be avoided but can be prevented / controlled with proper maintenance.
- Regular Inspection and check-up of Certain critical location of the plant is must.
- Standard Protection Techniques/coating has to be applied for various joints and couplings.
- Quality of water Circulation should be monitored specially in boilers and Cooling systems. Care should be taken while substituting failed components

DISTRIBUTED POWER SUPPLY BASED ON MODULAR HYDROGEN FUEL CELLS AT DIFFERENT SCALES

Prof. AK Singh
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ABSTRACT:
In order to reach the 1.5^{0}C temperature aim of Paris, the world need to develop different options how to produce and store energy in a sustainable way. Hydrogen is seen as a very promising green fuel or energy carrier for different reasons. The most effective way to convert the chemical energy of hydrogen into electrical energy and / or thermal energy is by the use of fuel cells. One key component of fuel cells is the bipolar plate. Especially for stationary cases, Unicorn Energy uses bipolar plates made of Aluminium, which is properly coated. By choosing an appropriate design of the bipolar plate and the fuel cell stack, it is possible to scale them in a wide range from 5kWel to 5MWel. Therefore, modular fuel cells can be a key technology for distributed power supply at different scales, e.g., from the residential market up to large industry buildings.

INTRODUCTION:

In the Adoption of the Paris Agreement of the United Nations Climate Change Conference 2015, the parties committed to pursue efforts to limit the temperature increase to 1.5°C [1]. To achieve this, it is necessary to reduce greenhouse gas emissions dramatically.

In light of the prevalent global trend for reducing carbon dioxide emissions and developing technologies of alternative energy sources that will displace and reduce fossil fuels, hydrogen will play an important role.

India is bullish on decarbonising its power sector and has set a target of 50% share of energy from non-fossil fuels by the year 2030. The Nationally Determined Contribution (NDC) communicated by the Government of India to the UNFCCC (United Nations Framework Convention of Climate Change) proposes about 50% cumulative electric power installed capacity in the country from non-fossil fuel-based energy resources by 2030. It assumes significance in view of Indian Prime Minister Shri Narendra Modi's pledge at the COP26 Climate Conference in Glasgow that India will achieve net zero carbon emissions by 2070.

For energy and industry sector, the following has to be considered: During burning process of fossil fuels like coal, oil or gas the greenhouse gas CO_2 is emitted. This means that for future applications renewable fuels like hydrogen come into focus. In Chapter-11 "Industry" of the latest IPCC report, e.g., it is stated that: ***Using electricity directly, <u>or indirectly via hydrogen from electrolysis</u> [..], offers many options to reduce emissions.*** *[2]*

This has mainly two reasons: First, if hydrogen is produced by electrolysis with green energy (e.g. solar or wind energy), no greenhouse gas is emitted and second, the "raw material" for hydrogen is water.

The optimal method to convert the chemical energy of hydrogen into electrical energy and thermal energy is by the use of fuel cells. Therefore, fuel cells are seen to be a key technology for the future for mobility sector and for stationary sector, e.g., in chapter 6 "Energy Systems" of the latest IPCC report [3]. The scope of this paper focuses on modular hydrogen fuel cell systems for stationary sector developed by Unicorn Energy. Hydrogen Fuel Cells find very promising application in energy technology for supplying energy to places in remote and inaccessible terrains where free access to power grid is not possible. With market grow and price reduction, it will be also a viable technology for grid connected applications.

FUEL CELLS

In Figure 1, a schematic of a single fuel cell is presented. Besides other elements, the main components of a typical single hydrogen fuel cells are:

- the bipolar plate, which has to
  - o be electrically and thermally conductive;
  - o provide a hydrogen flow field to distribute hydrogen;
  - o provide an oxygen flow field to distribute oxygen;
  - o provide water flow field to distribute cooling water;
  - o provide means for sealing;
  - o be resistant against corrosion.

Therefore, the bipolar plate is a critical key component of a fuel cell where typically a lot of effort is used to choose the right design.

- the gas diffusion layer to distribute hydrogen and oxygen homogenously over the whole area;
- catalyst coated membrane (CCM) which provides the electrolyte, anode and cathode of the single fuel cell.

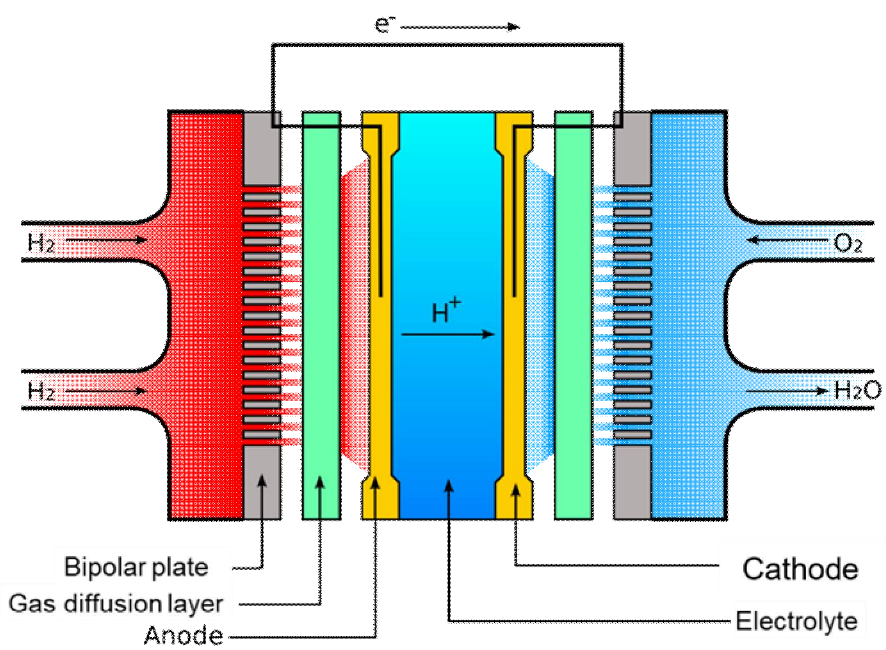

Fig-8: Schematic of a fuel cell [4]

Fuel Cells by Unicorn Energy are Low Temperature Proton Exchange Membrane (PEM) Fuel Cells.

Typical parameter of a single hydrogen fuel cell are 0.7V and 0.7 A/cm² for each cell.

Modular Hydrogen Fuel Cells and Fuel Cell Systems

To increase power of a fuel cell Unicorn Energy has three different options with its technology:

1) Increase the number of cells in each stack
2) Connect the Stacks electrically in series
3) Connect the fuel cell systems parallelly through the grid

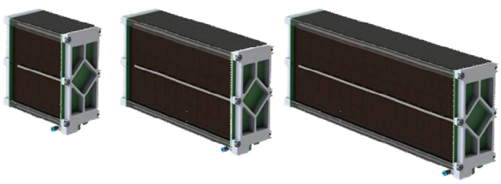

Fig-9: Three fuel cell stacks with different number of cells

First, by stacking the single fuel cells into a fuel cell stack, the power of each stack is mainly defined. The area of a single cell defines mainly the amperage, the number of fuel cells defines the voltage. As an example, Fig.-2 shows three fuel cell stacks, designed by Unicorn Energy, with different number of cells. Typical numbers for the electrical power are about 5 kWel – 50 kWel.

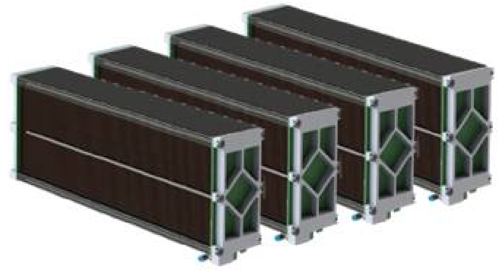

Fig-10: Four fuel cell stacks connected in series

Second, by scaling the fuel cell stacks in series, the power of one fuel cell system can be increased. As an example, Fig.-3 shows four fuel cell stacks connected (electrically) in series. Typical numbers for the electrical power are about 20kWel – 200kWel.

Fig-11: Four fuel cell systems connected in parallel on AC or DC grid

Third, by scaling each system in parallel (independent, if on AC or DC grid), the power of the whole system can be increased. As an example, Fig.-4 shows four fuel cell systems connected in parallel. Typical numbers for the electrical power are about 200kWel–2 MWel in parallelly connected systems.

Distributed Power Supply

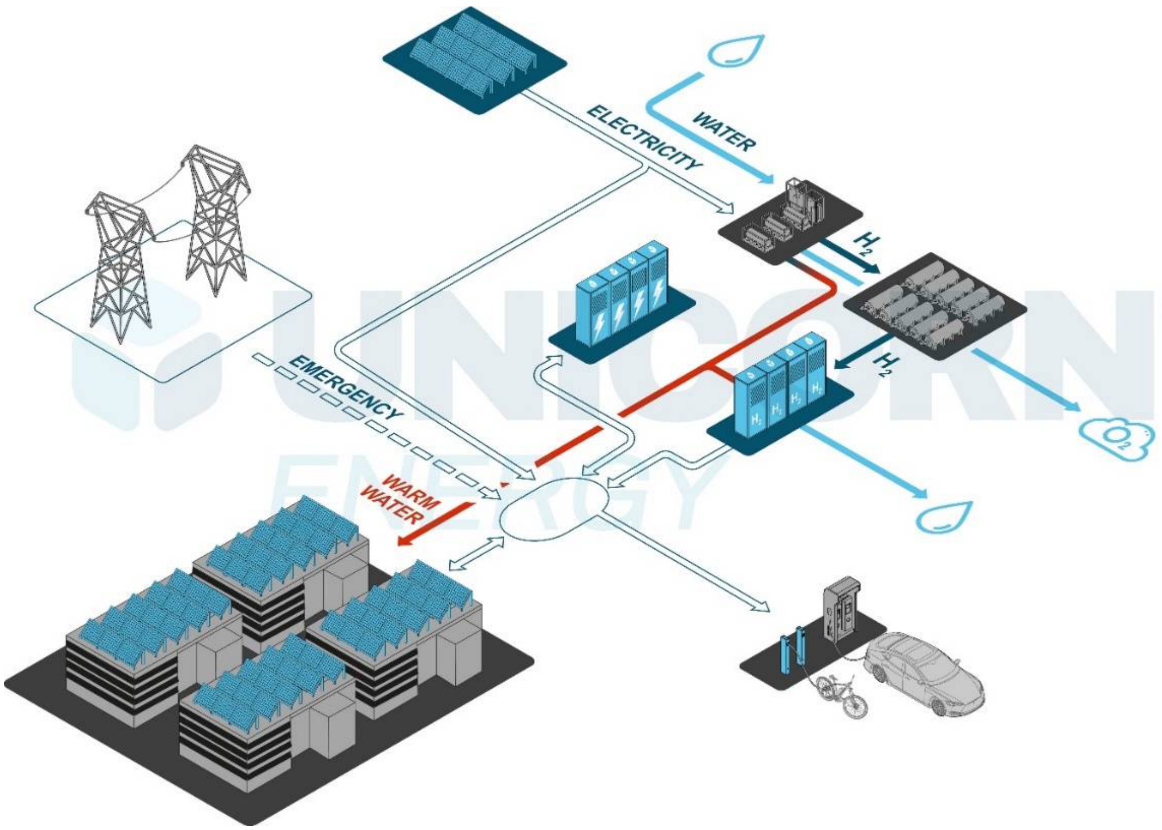

Fig-12: Power supply network

Fig.-5 shows a schematic (distributed) power supply network for four buildings.

With the input of solar energy and water, green hydrogen can be produced by an electrolyser. By-products are heat and oxygen. Hydrogen can be stored in hydrogen tanks. The stored hydrogen can be used by the stationary fuel cells to produce electricity and heat. By-product is water. In the supply network, there will always be a battery storage for buffering electricity peaks efficiently.

Dependent on the energy consumption of the buildings and the geographic region, the sizes for energy sources, electrolysers, hydrogen tanks, fuel cells, battery storages should be calculated individually. But with these components, it is possible to build up distributed island networks.

Intersections with Metallurgy

Unicorn Energy chose aluminium as raw material for the bipolar plate as it has good properties regarding electrically and thermally conduction, weight, and costs.

Disadvantages regarding resistance against corrosion can be overcome by the right coating.

Typical need of aluminium for bipolar plates is 2500g per $1kW_{el}$, meaning 2500kg per $1MW_{el}$.

During production of bipolar plates tolerances are the critical aspect because of sealing and possible leakage of hydrogen. Processes should be able to produce structures < 1 mm with tolerances <0,05 mm

To save transport costs, it could be feasible to locate the fuel cell production next to the raw material production of aluminium.

Conclusion

Unicorn Energy provides modular hydrogen fuel cells which can be used for distributed power supply at different scales. These fuel cell systems shall be used together with other product like electrolysers, hydrogen tanks and battery systems to secure autarchy. Distributed power supply based on green hydrogen and modular hydrogen fuel cells can be one key to reach the 1.5^0C temperature aim of Paris Agreement.

One important component of the fuel cell of Unicorn Energy, the bipolar plate, is made of aluminium – and therefore production capacities of the fuel cell may be placed next to the raw material production. This technology is the most preferred one for India as Aluminium is available in abundance at very reasonable price in the country.

MODULAR WEAR PROTECTION AND REPAIR WELDING IN POWER PLANTS

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How a Coal-fired Power Plant works?

Electricity is produced in India through Fossil fuel, Solar, Hydro, Wind or even Nuclear means. Here we focus on modular wear protection, coatings and repair welding mainly at coal-fired fossil plants where the process involves heating of water in a boiler to produce steam. The steam, under tremendous pressure, flows into a turbine, which spins a generator to produce electricity.

The modular metallurgical solutions, coatings or repair welding could similarly provide solutions for all type of other power generating plants too.

Process involved in a Coal-fired power plant.

Coal Handling Plant

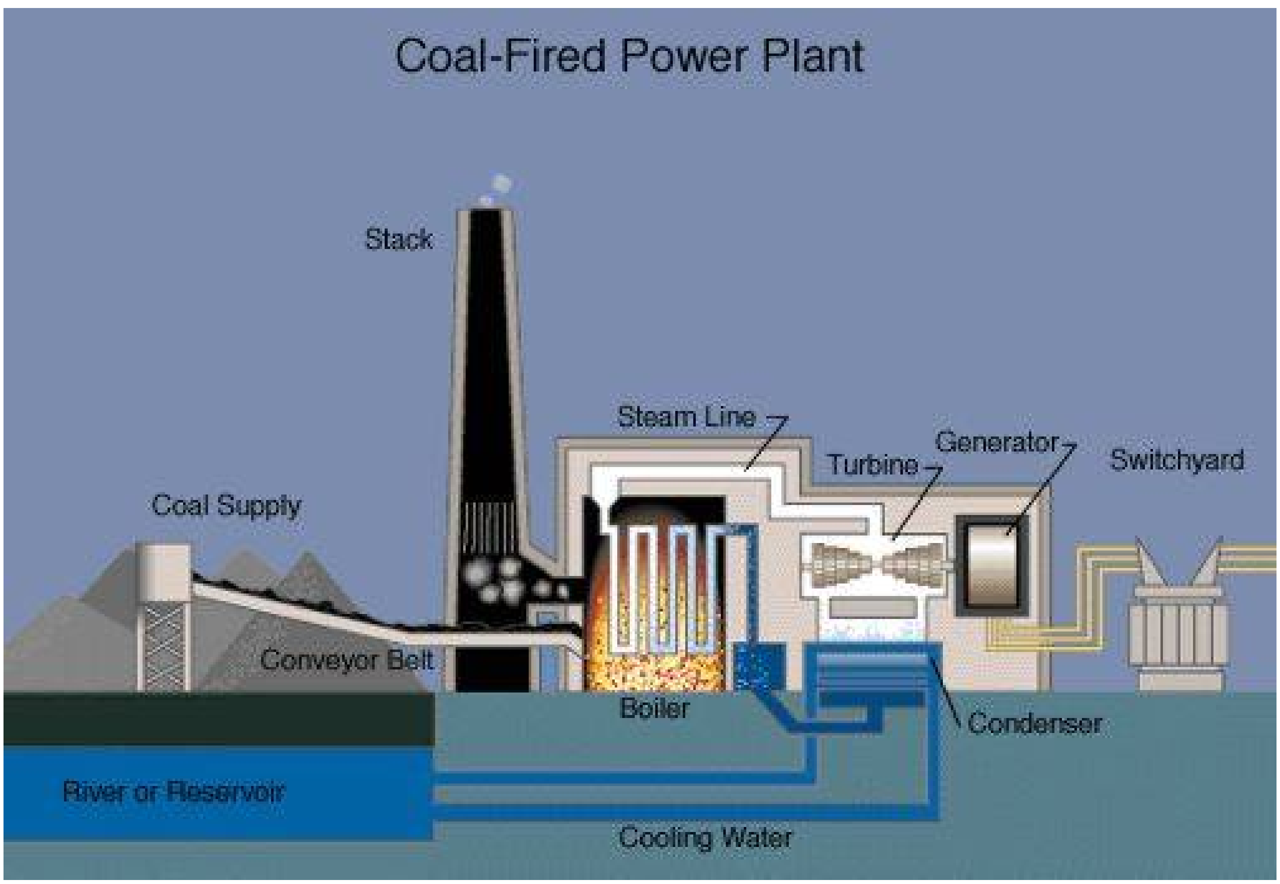
With over 150 coal-based power plants, India is producing 1.8 lac Mega Watts of electricity. Large quantities of bulk material are handled by the mining, conveying, crushing, and feeding systems for boilers in power plants. If they are not adequately protected, these systems will frequently fail, necessitating repair or replacement with appropriate metallurgy.

The broad terms "wear" and "erosion" relate to processes that cause damage as a result of abrasion and impacts from solid and liquid particles. So, metallurgy is important during design, refurbishment and repair in a number of technological areas of thermal plants.

We must consider these aspects into considerations when developing plants from a metallurgical perspective because internal components of plants frequently operate up to 140% above their planned capacity.

This is all the more necessitated as majority of the coal in India is of poor quality and contains a sizeable amount of mineral matter that is mostly incombustible. The primary causes of power plant component degradation are quartz (SiO2) and the alumina-silicates found in coal.

The service circumstances, in addition to the material composition, have a big impact on how quickly the components age. Due to interactions with abrasive media like silica/coal particles, material characteristics including hardness, fracture toughness, and microstructure also play a key influence in material deterioration and/or removal. At the power plants, different forms of wear happen at particular places in the system.



COAL HANDLING PLANT

Fuel (received by rail, barge, or overland conveyor)

Stockpiled → Reclaimed & conveyed (into Silos, Bins, and/or Bunkers) → Fed into mill or directly into combustion zone

↓

Residues—both bottom ash & fly ash—collected in Cyclones, Bag houses & electrostatic precipitators & then usually stored in large Silos.

Ultraslide S nonstick coating for fine coal Tanks cars

Xtrasmooth Liners for uncrushed coal.
Expected life: 3-4 times of regular lining with better flowebility.

Bunkers

The flow properties of bulk material demand that a prerequisite for bunker design is the provision of low friction hard wearing liners for the bunker walls. The options available here are polymer liners, low friction epoxy based coatings, ground composite wear liners and cast basalt tiles. The four materials with their properties are given below on 1-5 scale.

	Abrasion Resistance	Impact Resistance	Stick Resistance
Cast Basalt	5	2	2
Epoxy Coating	4	3	4
Polymer Liner	3	3	3
Composite Wearplate	5	5	5

- For particle size up to 20mm, our Ultraslide S coating may be a good solution.
- **Xtrasmooth liners** could be used. They are having smooth surface with coefficient of friction of only 0.18 where stainless steel is 0.24. Further it outwears stainless steel by 06-08 times.

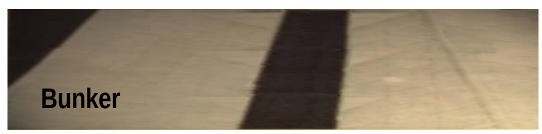
At one of the power station, six 1000T boiler feed coal bunkers have been lined with **Ultraslide S** high-grade surface coating. The 600MW station has an average coal throughput of 4000T/Day and previously many problems were caused by poor flow rates.

When correctly applied, **Ultraslide S** coating should have a minimum life of five years on both concrete and steel bunkers dedicated to coal handling. It has a good adhesion to steel and concrete and its stick-resistant surface is self-polishing and resistant to corrosion and chemical attack.

Coatings are completely seamless and easy to apply using brushes or airless spray equipment; thickness can be built up and varied to give additional protection in areas subject to highest wear, such as in the throat of a hopper.

Additional coatings can be of a different color enabling maintenance engineers to see at a glance the rate of wear and predict exactly when maintenance will be required.

The coal flow is stopped overnight, except for emergency power requirements; this really puts the **Ultraslide S** coating to the test when flow is re-introduced each morning.



Similarly, the ***mill outlet elbow*** (as in photograph) and ***mill discharge valves*** guides the pulverized coal and in the process it undergoes heavy erosion.

X'TRARESIST epoxy compound up to 15mm thick was employed to resist this erosion

X'TRARESIST lined elbow has been in service at one of the power station in the western India for more than 8,000 hours whereas earlier life with hard facing electrodes was never more than 5,000 hours

The Coal based power stations handle massive quantities of coal right from getting the coal from the mines to the conveying of the coal through ***conveyors/hopp-ers/chutes*** and finally they are being pulverized in the mills before firing into the boiler.

The photograph shows the ***flap gate*** which is used in the coal handling plant of the power station to divert coal from one stream to the other. In the process, because of the heavy impact and abrasion it experiences excessive wear.

Using X'TRALIFE WEARPLATE of Grade XL-TIMP, the same is in service for more than 2 years whereas earlier flaps made from Stainless steel used to puncture within 6 to 8 months.

WRTPL's XL-800 FC tungsten carbide in Nickel matrix provides superior resistance to wear from abrasion, corrosion, and erosion, even under conditions of impact or elevated temperatures.

The **Coal Fly Ash**, one of by-products, can be very difficult to handle.

Fly ash, as it is produced from the combustion of coal is ***hot, very corrosive,*** *and quite* ***abrasive***. In order to capture and transport it to a containment system prior to final disposition, material-handling fans are often used to provide the motive force. These are normally induced draft fans with air-foil blades.

Due to the hot, corrosive conditions and the abrasive nature of fly ash, the fan, and especially the fan blades, are subject to erosive, abrasive and corrosive wear.

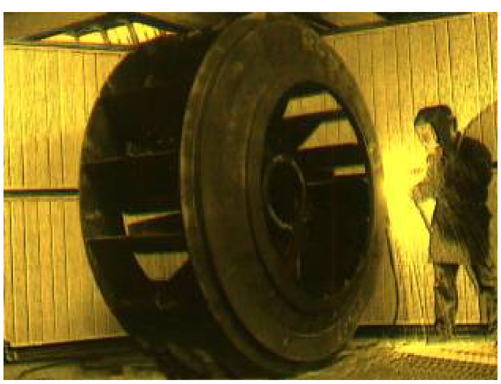
The fly ash is typically transported at a velocity of 3,000 to 4,000 feet /minute. Impingement of that gas stream on a component can cause failure due to wear in a very short time.

Fan Liner Protected with Chrome Carbide weld overlay after 4 months service.

Fan Liner protected with WRTPL's **XL-800FC** in the same application after 12 months service.

Advantages

- Metallurgical bond
- Tungsten carbide loading in Nickel Matrix.
- Resists chipping & spalling
- Reduced weight
- No check cracks porosity



Wear protecting a rotating device, such as Fan Blades, include weight & balance; so, cladding the wear-prone surfaces with a weld overlay means the addition of significant weight, & the application process for weld overlay leads to inherently uneven deposition since it is very dependent on operator skill which will lead to an out-of-balance situation for the fan.

The use of thermal spray coatings, while capable of adequate abrasion protection, do not stand up well to corrosion or impact, such as when a "clinker" impinges on the surface of the component needing protection. Wear protective tiles of ceramic or tungsten carbide are susceptible to erosion at the joints, destroying the adhesive and causing the tiles to fall off, creating an imbalance and leaving an area of the blade unprotected.

Wearresist's XL-800 FC gives ultrathin layers with no above mentioned limitations and excellent life

Another critical area of wear in PF and CFBC boiler is boiler tubes. WRTPL SVCC cladding technology has given excellent performance and ensured 9,000 hrs. and more life as against 3,000-6,000 hrs. without cladding.

SVCC –Supersonic Velocity Continuous Combustion process a unique thermal spray cladding utilized for in-situ applications.

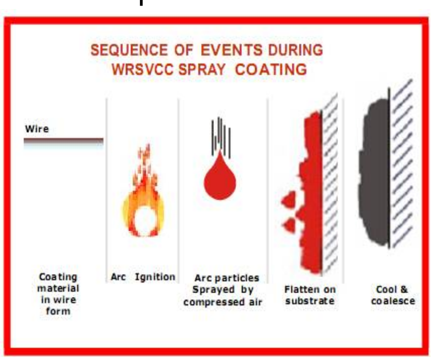
A Supersonic velocity thermal spray process is one where the material is atomized and / or accelerated under supersonic gas velocities (greater than the speed of sound). For this reason the energy of the gas stream is focused directly on the material to be sprayed, producing a coating that has low permeability, and has a homogeneous coating structure than a low velocity coating. Further the bonding strength is excellent.

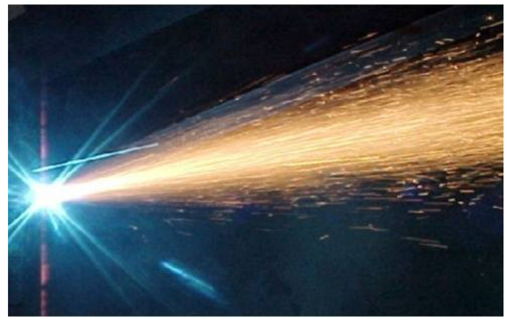
Before coating

After coating

Process Details

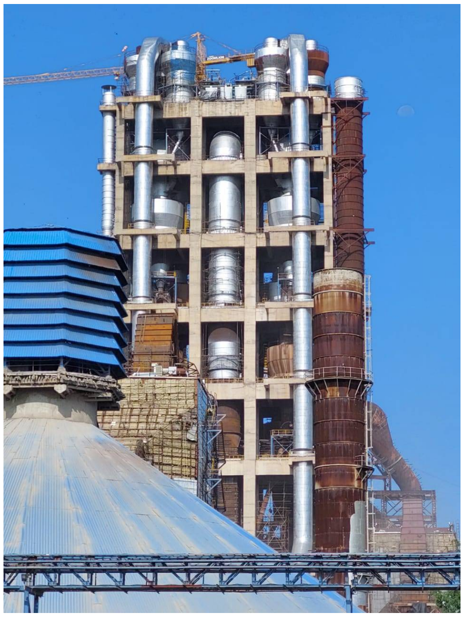
- ❖ SVCC Technology: Supersonic Velocity Continuous Combustion Process.
- ❖ SVCC Process is one where the material is atomized and/or accelerated under super-sonic gas velocities (greater than the speed of sound).
- ❖ That produce coating has low permeability and has a homogeneous coating structure.
- ❖ Excellent bonding strength and Corrosion protection.





Application Photos after Aluminizing by SVCC – External

- Protect Outer Surface from corrosion
- Increase Life of Stacks, Vessels, ducts
- Reduces Heat Radiation
- Save Energy and Fuel Consumption
- Improve aesthetic view of the Plant



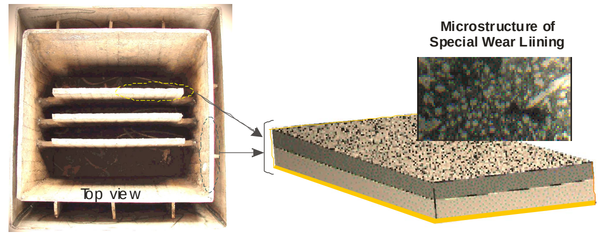
Similarly, the ***burner tip*** which is at the tip of the firing system into the boiler and is exposed to heavy erosion at temperatures upto 1200^{0}C. Normally power station uses stainless steel 310 fabricated tips with hardfacing by electrodes. **X'TRALIFE WEARPLATE** of Special Metallurgy in stainless steel, as backing, was used in one power station of the in the Northern India, one power station of the NTPC and in one power station of the PSEB; and, the life extension of 2 times had already being achieved. The ***tip*** manufactured from X'TRALIFE WEARPLATE is shown in photograph

Yield Strength- 60Kgf/mm^2

Operating temp- 1200^{0}C

Hardness – 63-65 HRC

Coefficient of Friction – 0.18gm



Other Applications

Premature discarding of worn-out components and tools (Fig.) is not just an expensive exercise from a financial point of view. The manufacturing of new parts to replace those tossed on the scrapheap represents a scary drain on the earth's depleting supplies of energy and essential raw materials.

The great majority of these parts could have had their working life prolonged significantly many times over by on site repairs. New generation superior Ultrafine car-bide alloys with glassy micro-structure can extend wear life by 2-3 times over conventional complex carbide hard facing.

Application	Base Metal	Problem
Points & Crossings	Mn. Steel	Abrasion + Impact
Wagon tippler gear	Cast Steel	Abrasion + Impact
Bunker chute	Triscol	Abrasion
Reclaimer wheel	Mn. Steel	Abrasion
Dozer arms	Forged Steel	Heavy impact
Crusher Ring	Mn Steel	Abrasion + Impact
Track Pads	Mn. Steel	Abrasion
Track links	Mn. Steel	Frictional Wear
Idler	Mn. Steel	Frictional Wear
Rollers	Mn. Steel	Abrasion + erosion
Coal hammers	Mn. Steel	Impact + Abrasion
Bullring Segment	Cast Steel	Abrasion + erosion
Coal mill vertical shaft	Alloy Steel	Erosion
Coal Mill Table	Ni Hard/High chrome	Abrasion + erosion
Coal bend	Cast Iron	Fine particle erosion
Boiler feed pump	Alloy Steel /Cast Iron	Cavitation
Coal burner nozzle +Tips	SS 310	High temp erosion
I D Fan blades + Shaft	Steel	Abrasion + erosion
Slurry Pumps + Impeller	Ni Hard	Silt erosion
Springs	Spring steel	Shock
Volute Liner	Ni Hard	Erosion

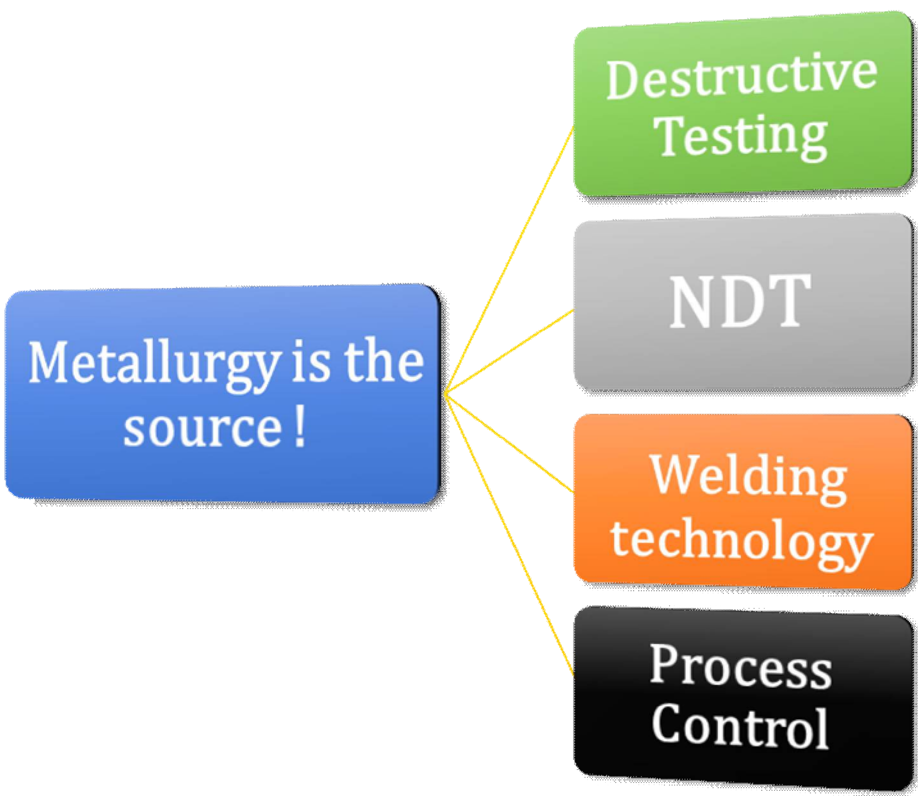
Conclusion

- WRTPL aims to provide wear & tear solutions resulting into improved machine availability and reduced shutdown costs to the power plants either of fossil fuel type, hydro, solar or even nuclear both for maintenance and new spares.
- Solutions include metallurgical upgrades to existing equipment materials to handle new aggressive minerals, corrosive media, high temperature in the system for optimum service life. The alloys can resist multiple stress factors on different applications.
- WEAR MANAGEMENT through X'TRALIFE Modular products has assisted the industry in adding value to their efforts to remain highly competitive.
- WRTPL has a full-fledged R&D team that is always creating high-tech solutions to meet the demands of the industry.

METALLURGICAL ASPECTS IN THERMAL POWER GENERATION

Vinay D Gaddu
Adani Power, Ahmedabad

- **Unpredictable and new Failure modes**
- **Difficult to standardize degradation due to varying O&M practices.**
- **Very few Competent Manufacturing and Testing agencies**
- **Very little technical advisory support from Technical bodies**

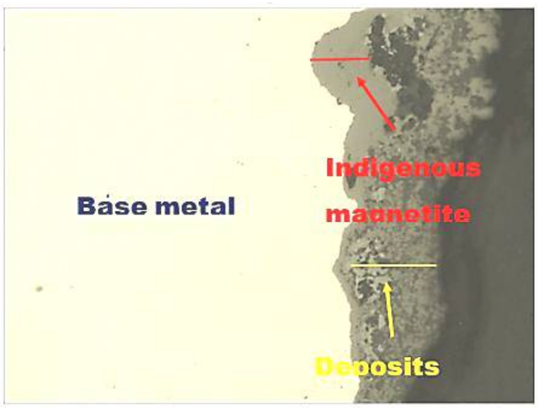


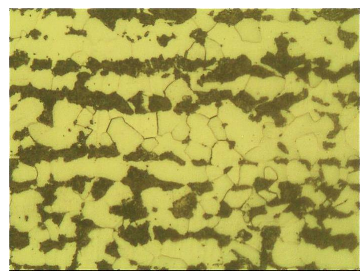
DESTRUCTIVE TESTING

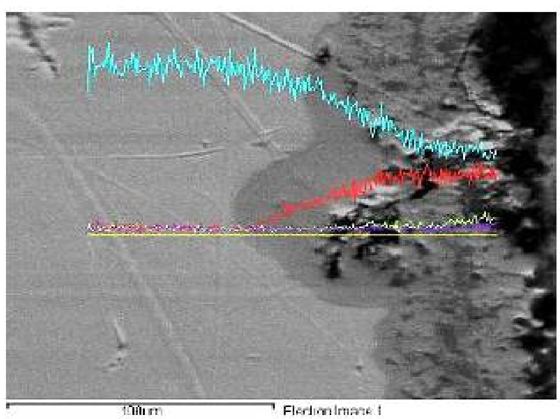
Tests in Waterwalls

International Association for Properties of Water and Steam - IAPWS

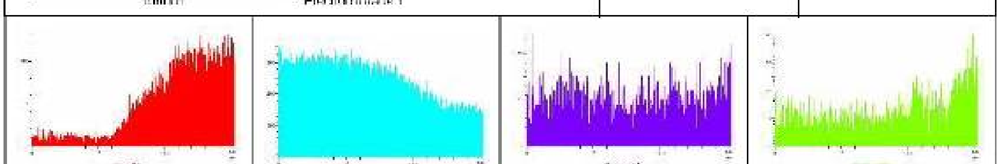
1. Level of total internal density (overall loading) in mg/cm^2 using the ASTM D-3483.
2. Optical metallography through the tube, indigenous magnetite and deposit.
3. Total thickness of the indigenous magnetite & deposits
4. Scanning electron microscopy & elemental mapping





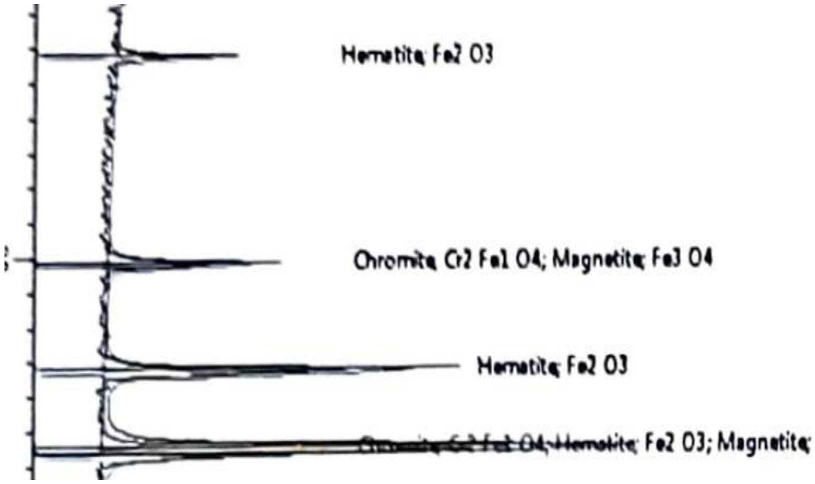


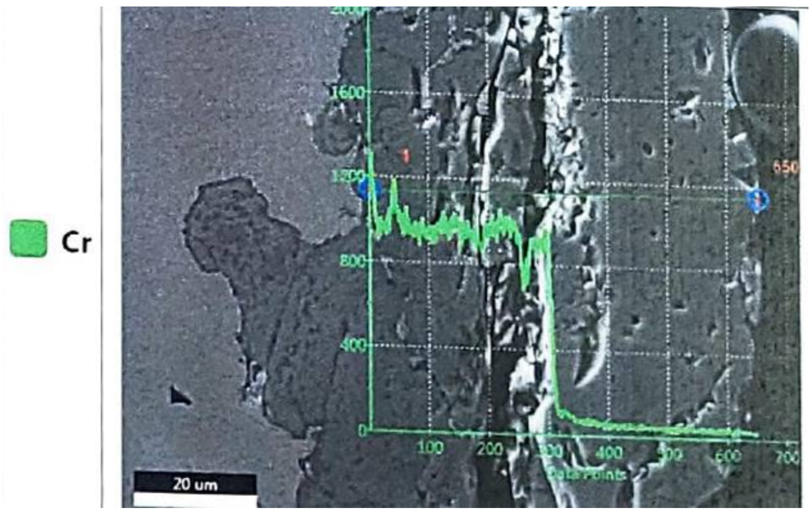
Elements	Average (%)
Oxygen	4.54
Iron	93.19
Phosphorous	1.69
Manganese	0.58



Oxygen	Iron	Phosphorous	Manganese

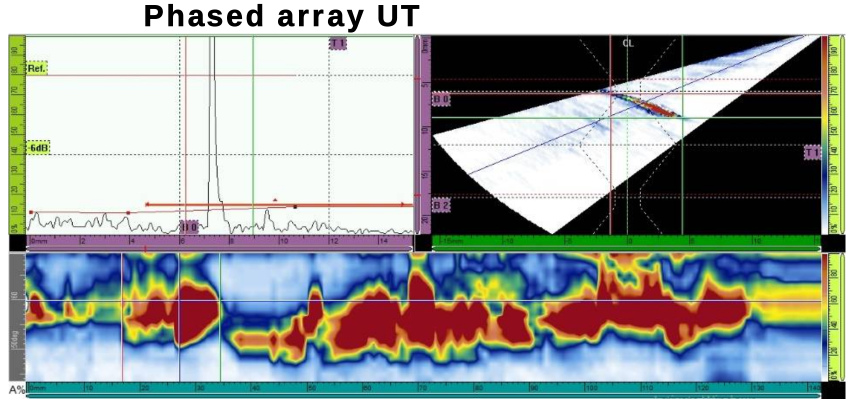
Detecting exfoliation

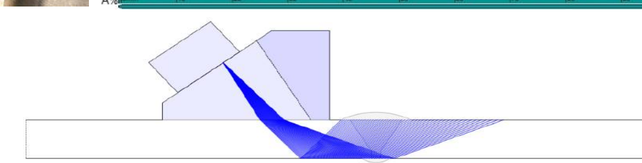


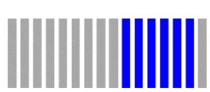


NDT

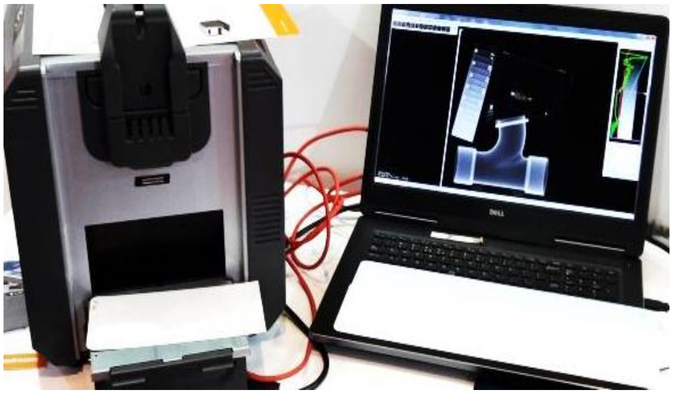
Phased array UT

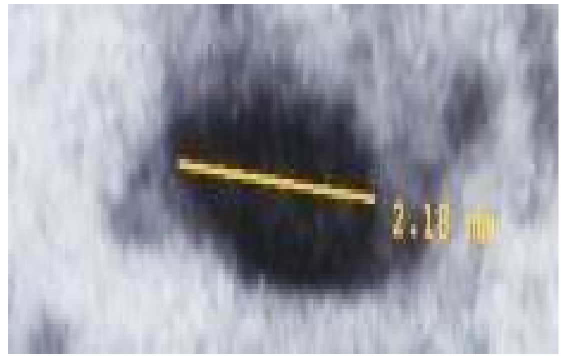






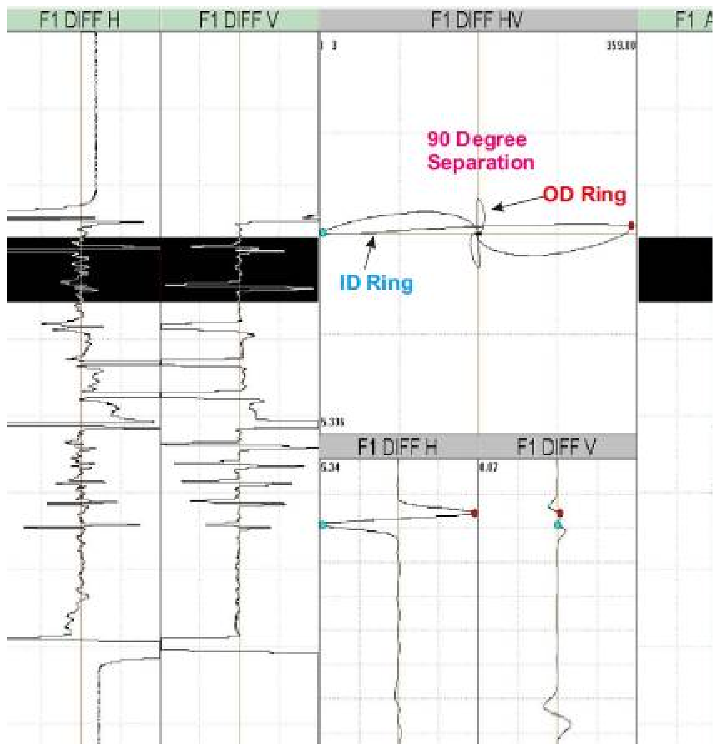
Digital RT



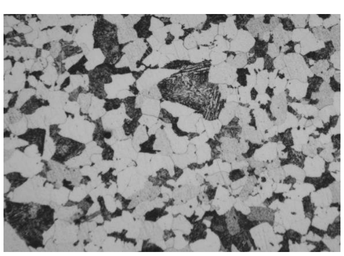


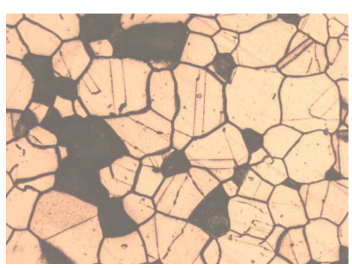
Eddy current testing of Heaters and condensers

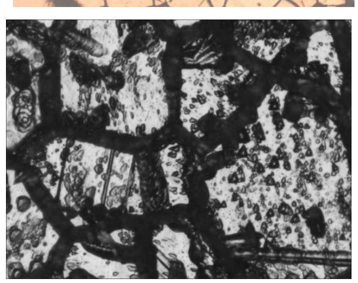
- Differential mode- pits, cracks
- Absolute mode- General wall loss.
- Around 2000 tubes can be inspected in 10 hour shift.
- Calibration is of UTMOST IMPORTANCE!

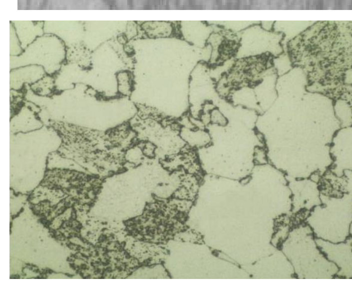


Replica – Micrographs









MECHANIZED BEVELING IN WELDING

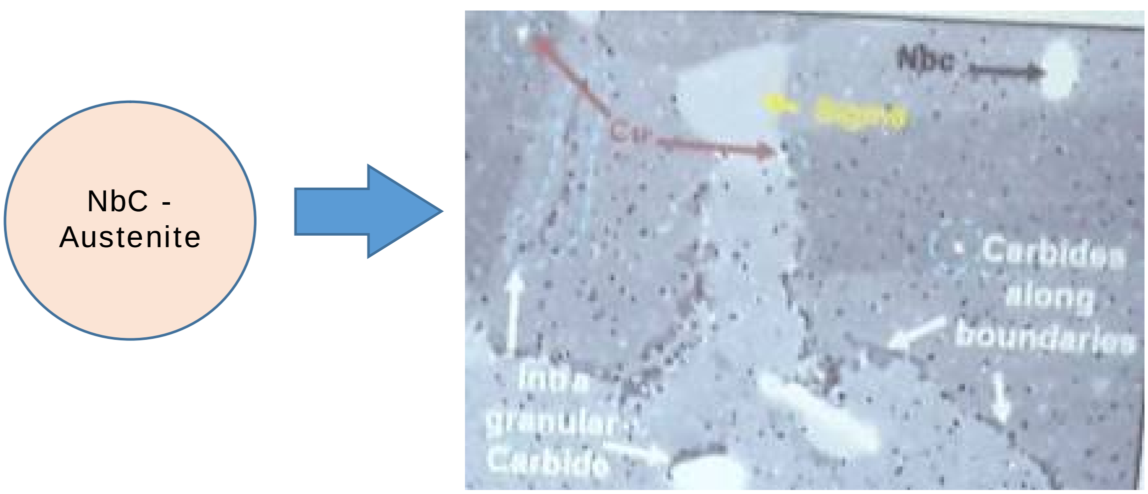
Mechanized weld joint preparation of tubes and piping

PROCESS CONTROL

Blades: EAF→ LF / VD → Ingot→ ESR??
12%Cr, 1W, 0.5Mo, 0.25V

Delta ferrite: 2% maximum. Lowers the crack propagation and initiation energy.
Alumina -silicate inclusions acts as stress riser for crack initiation.

Super 304H – keep B and Nb at higher range limits to reduce σ



Witness tests and monitor test certificates

Main dimensions : 48MM OD×8MM THK×12000MM LONG
Tube ends : PLAIN ENDS
Surface treatment details(SS only): PICKLED&PASSIVATED
Tolerances:

Main dimensions	Tolerances
48MM OD×8MM THK×12000MM LONG	OD:+/-0.20 MM THK: -0 to +22% LENGTH: +6MM,-0

Mechanical Tests :

Direction :Longitudinal Gauge Length =50mm	Tensile.Strength. (Mpa)	Yield.Strength. 0.2% (Mpa)	Elongation % GL= 50mm
As per specification : Values (Minimum)	515 MPa	205 Mpa	35%
Test results	650,660	275,290	59,58

Bend test: Not Applicable
Flattening test : ACCEPTABLE
Crushing test : Not Applicable
Flaring test : ACCEPTABLE
Flange test: Not Applicable
Bend test on weld :Not Applicable
Bulging test and drifting test (for copper and brass): Not Applicable
Grain size (According to ASTM E112) :7.5 ACCEPTABLE
Hardness (≤90 HRB) :80,80,82
Heat treatment: SOLUTION ANNEALED AT 1100 DEG C& WATER QUENCHED
Hydraulic test Substituted by ET,Acceptable
Eddy current test AS PER ASTM E426: Acceptable

BOILER TUBES ALLOYS OF FUTURE ....

Tempaloy: 18Cr, 8Ni, 3Cu, 0.1Ti

S30432: 19Cr, 10.5Ni, 0.6Nb, 3.5Cu, 0.12N

SA213TP310HNbN: 27Cr, 23Ni, 0.6Nb, 0.35N

METALLURGICAL ASPECTS OF LECTRICAL CONTACT MATERIALS USED IN POWER SECTOR

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Faculty of Technology and Engineering,
MS University of Baroda, Vadodara

Introduction:

A power plant consists of variety of electrical equipment such as:

- Generators
- Alternators & Exciters
- Bus bars
- Synchronizing equipment
- Switchgears like Circuit Breakers, Relays and protection devices
- Power transformers, CT & PT
- Isolator and Earthing equipme-nt etc.
- Control and regulation of ele-ctrical power is generally done by switchgear devices
- These switching devices incor-porate components known as contact materials
  whose function is to
  - connect current paths
  - carry the current in closed position and
  - to interrupt the current as and when required

Switchgear devices are of two types namely,

- low-voltage switchgears (up to 1,000 V)
- high-voltage switchgears (1,000 V & above)

Switchgear devices incorporating electrical contacts are:

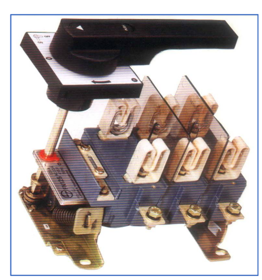
- Circuit breakers (ac & dc, ACB, OCB, VCB, SF6, MCB, MCCB, ELCB, etc.)
- Contactors (ac & dc)
- Relays (electromagnetic, indu-ction and thermal type)
- Switches (rotary, knife and selector type)
- Switches (isolating, earthing and current limiting type)
- Various types of Fuses

Commercially Used Typical Switchgear Devices:

Air Cicuit Breaker

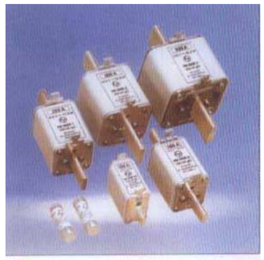
MCCB

Contactor



Switch Fuse

Protection devices



HRC Fuses

Contacts used in switchgear devices:

Three types of contacts

- Switching or *make - & - break* contacts, also known as the arcing contacts
- Sliding contacts or Brush materials
- Stationary contacts like Bus bars

Classification of electrical contacts on the basis of power rating

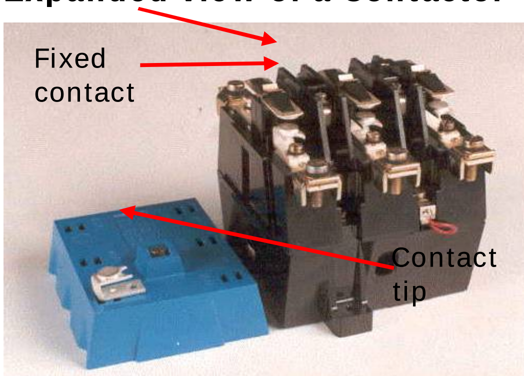
Sr. No.	Type of contacts	Current-carrying capacity	Typical applications
1	Very Light duty OR Feeble duty	Few mA to 1A	Electromagnetic current and voltage relays, radio and telephone relays, micro-switches etc.
2	Light duty	Up to 10A	Contactors and relays, control switches etc.
3	Medium duty	10A to 300A	Rotary switches and slip rings
4	Heavy duty	> 300A and up to several thousand amperes	Oil circuit breakers (OCB), air-blast circuit-breakers (ACB), sulfur hexafluoride (SF_6) circuit- breakers, vacuum circuit breakers, etc.

Typical Shapes of commercially used Contact Materials:

Contacts for Low-voltage switchgears

Contacts for High-voltage switchgears

Expanded view of a Contactor



Considerations involved in selection of Electrical Contact Materials

Physical Properties of Contact Materials:

- Density of the material
- Microhardness
- Microstructure

Contact properties:

- Arc erosion
- Contact resistance
- Contact welding

PROPERTY REQUIREMENT FOR CONTACT MATERIALS

Physical properties

- High electrical conductivity
- High thermal conductivity
- High melting & boiling point
- Good thermal stability

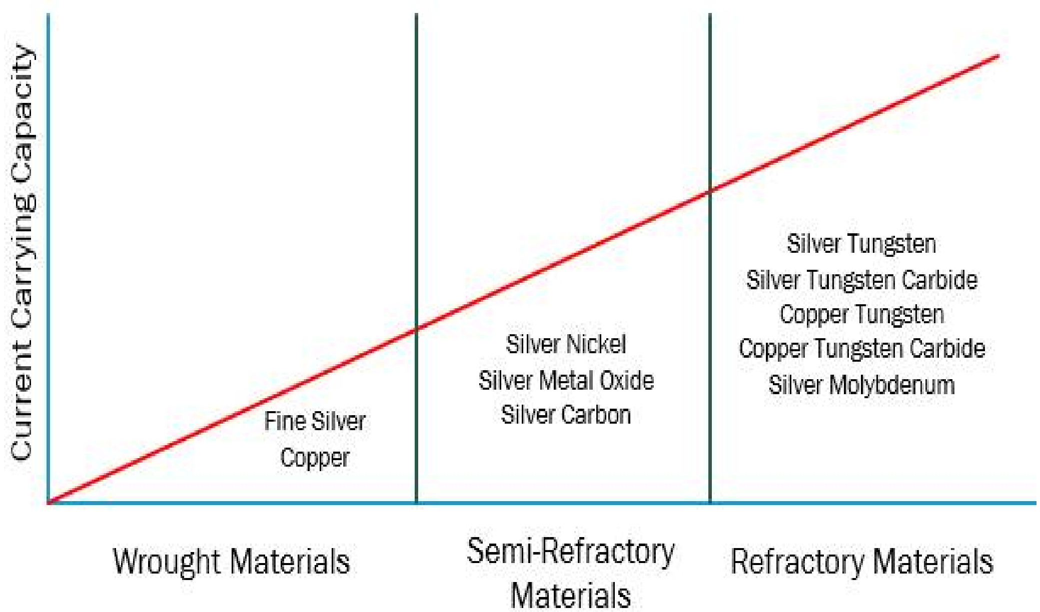
Contact properties

- Low arc erosion & mechanical wear
- Low contact resistance
- Resistance to contact welding

Thus no single metal can have combination of all these properties, and hence a wide variety of materials have been developed as electrical contact materials.

Materials for Electrical Contacts

Selection of contact material on the basis of its current carrying capacity:



Classification of different materials used in electrical contacts:

Contact Materials

- **Pure metals**
  - Precious metals like Pt, Pd, Au, Ag
  - Base- metals like Cu and Al
  - Refractory metals like W and Mo
- **Alloys**
  - Alloys of precious metals like Pt-Ir, Pt-Rh, Au-Ag
  - Alloys of base metals like Cu-Cd, Cu-Cr, Cu-Be
- **Overlays & Bimetallics**
  - Clad, electro- and electroless deposited overlays of precious metals like Ag, Au, Pd, Pt, Rh, etc.
- **Composites**
  - Metal-metal composites like Ag-Ni, Ag-W, Cu-W
  - Metal-metalloid composites like Ag-C, Cu-C, Ag-Ni-C, Cu-CNT & Ag-CNT
  - Metal- metal compound type composites Ag-CdO, Ag-SnO_2, Ag-ZnO, Ag-NiO, Cu-CdO, Ag-WC, Ag-MoC

Pure metals as contacts:

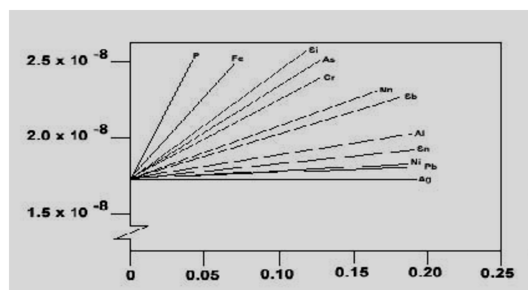
- Precious metals like Pt, Pd, Au, Ag as feeble duy contacts in microelectronics & telecommunication devices
- Base- metals like Cu and Al as bus bars with minor alloying additions
- Refractory metals like W and Mo in heavy duty contacts.

Precious metal alloys as contacts:

- Alloys of precious metals like Pt-Ir, Pt-Rh, Pd-Ru, Pd-Cu, Pd-Ag, Pd-Pt-Au-Ag, Au-Cu, Au-Ag, Au-Ag-Ni, Au-Ag-Pt, Ag-Cu, Ag-Cd, Ag-Pt, Ag-Pd, Ag-Mg-Ni, etc.
- Offer an extraordinarily high resistance to oxidation, Sulfidation/tarnishing & chemical corrosion but have low strength and hardness
- Used as very light (feeble) duty contacts in radio and telephone relays, miniature micro switches and contacts for electronic applications

Base metal alloys as Contacts:

- Alloys of base metals like Cu-Cd, Cu-Cr, Cu-Bi,Cu-Ag, Cu-Be
- Offer high strength, high hardness and good resistance to mechanical wear but at the cost of loss of electrical conductivity
- Suitable for medium to heavy duty applications depending on the material used.



Effect of alloying elements on resistivity of copper

Copper and Aluminium as Contacts:

- Copper is a soft, malleable and ductile metal and has high thermal and electrical conductivity
- The electrical conductivity of copper is second only to silver, being equal to 100% IACS (100% IACS = 58 micro.Ohm. cm)
- Aluminium is next to copper, because of its good electrical conductivity, low density,

ready availability and low cost

- The EC grade of aluminium has reasonably good electrical conductivity (61% IACS)
- Oxidation is a major issue for Cu and Al contacts

Tungsten & Molybdenum as Contacts:

- Tungsten & Molybdenum are used as contact material since long
- Because of its high melting point (3410^0C) and boiling point (5930^0C) along with high hardness, Tungsten gives excellent resistance to arc erosion, sticking and welding
- But the main problem with Tungsten or Molybdenum is its high specific resistance
- Used for 300A to several thousand amperes current in OCBs; SF_6 circuit breakers; vacuum circuit breakers; etc.

Composites as Contacts:

Various composites are used as

- ***make and break*** or arcing contacts
- ***sliding*** *contacts* or as brush materials
- Refractory metals like W or Mo have
  - high density & high hardness,
  - good resistance to wear **but**
  - poor electrical and thermal conductivity and
  - oxidation resistance
- On the other hand, Silver and copper, have
  - good electrical and thermal conductivity **but**
  - have greater tendency to erosion & wear
  - Metal like Ag or Cu and a refractory metal like W or Mo are combined to develope **composites as material for contacts**

- Metal-metal composites such as Ag-Ni, Ag-W, Cu-W, Ag-Ni-W, Ag-Fe, W-Cu, etc.
- Metal-metalloid composites like Ag-graphite, Cu-graphite, Ag-Ni-graphite
- Metal - metal compound type composites (i.e. Metal-metal oxide / carbide contacts)

Silver-metal oxide contacts:

- Silver-metal oxide (Ag-MeO) composites are used as ***make and break*** contacts under high current & / or voltage for low- & medium- duty applications
- They have more resistance to arc erosion & contact welding than pure silver contacts
- In Ag-MeO composites,
  Silver: acts as a matrix & provides good electrical conductivity **whereas**,
  Oxide phase: determines the switching behaviour of the device i.e. tendency to **contact erosion and welding**

Selection of the oxide phase based on Thermodynamic stability of metal oxide:

Oxide's type	Heat Kcal/ mol	Decom Position temp.(^{0}C)	Boiling Point (^{0}C)
CdO	66.4	1,000	1,85
SnO_2	135.8	1,625	2,250
CeO_2	233.0	1,390	-
La_2O_3	543.0	2,315	4,200
Y_2O_3	444.0	2,400	4,300
Bi_2O_3	136.8	›1,750	-

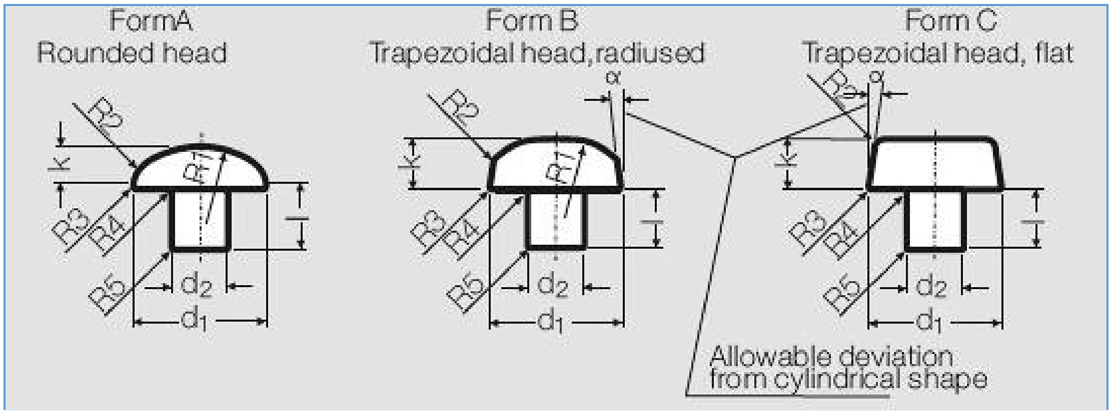
Various Silver-Metal Oxide (Ag-MeO) type contacts used in Switchgears are: ****as dopant*

Ag / CdO	Ag/SnO_2/In_2O_3 *
Ag / SnO_2	
Ag / ZnO	Ag / SnO_2 / Bi_2O_3
Ag / NiO	
Ag / CuO	Ag / SnO_2 / Sb_2O_3
Ag / In_2O_3	
Ag / Bi_2O_3	Ag / SnO_2 / WO_3

Overlays & bimetallics as contacts

- **Cladded**
- **Electroplated and**
- **Electroless deposited**

overlays of precious metals like **Ag, Au, Pd, Pt, Rh, etc.** as contacts



Sliding contacts & Brush materials

- Sliding contacts are used in electrical machinery for transfer of electric current between two members wherein one of the members is stationary whereas the other is moving e.g. a rheostat, carbon brushes, commutators & slip ring motors.
- e.g. All carbon, Cu-graphite or Ag-graphite brushes

Cu-CNT and Ag-CNT Contacts:

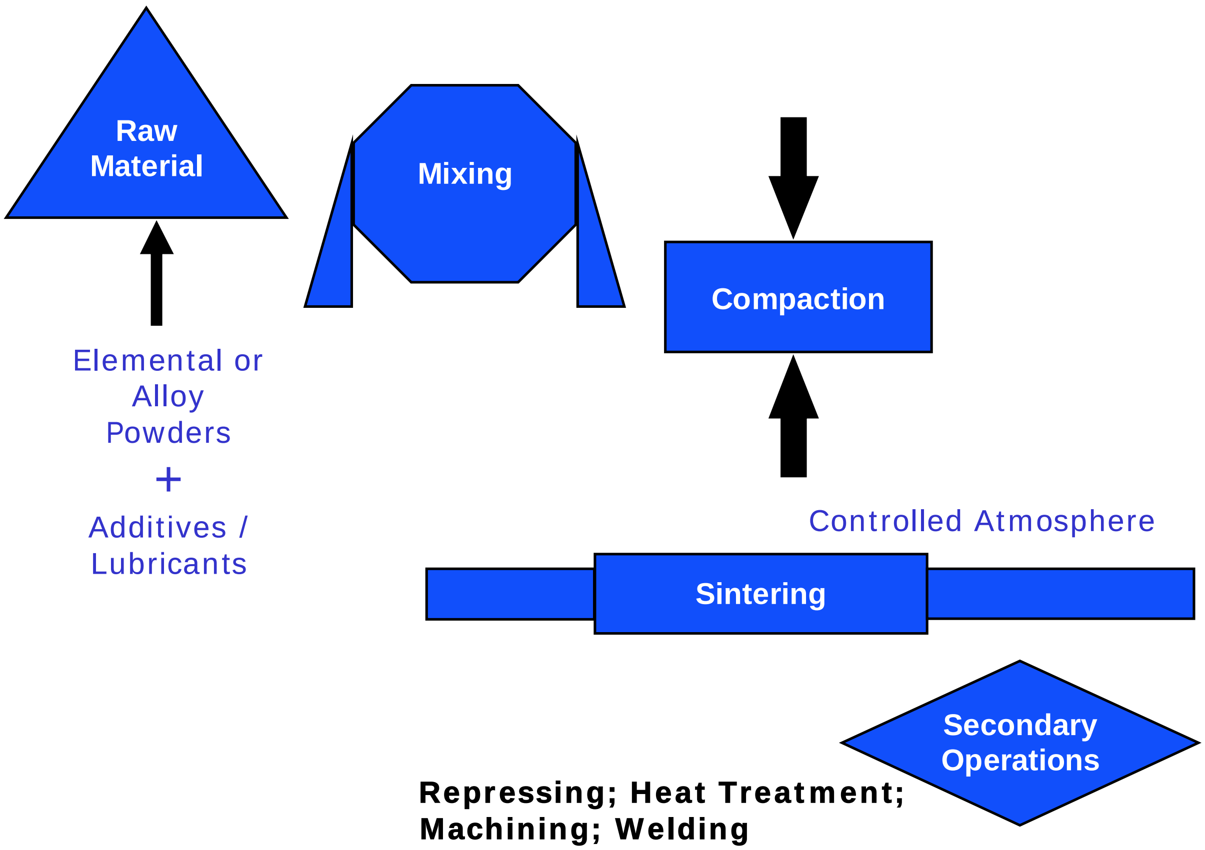
Why CNT?

- Very low defect concentration (1 defect in 10^{12} carbon atoms) and hence ballastic conduction
- High current carrying capacity 10^9A per cm^2 i.e.10^3 times higher than that of noble metals
- High melting point ~ 3800^{0}C
- High Young's modulus 1TPa i.e. 10^3 times that of diamond
- High thermal conductivity 6600 W per mK, i.e. more than twice of diamond.

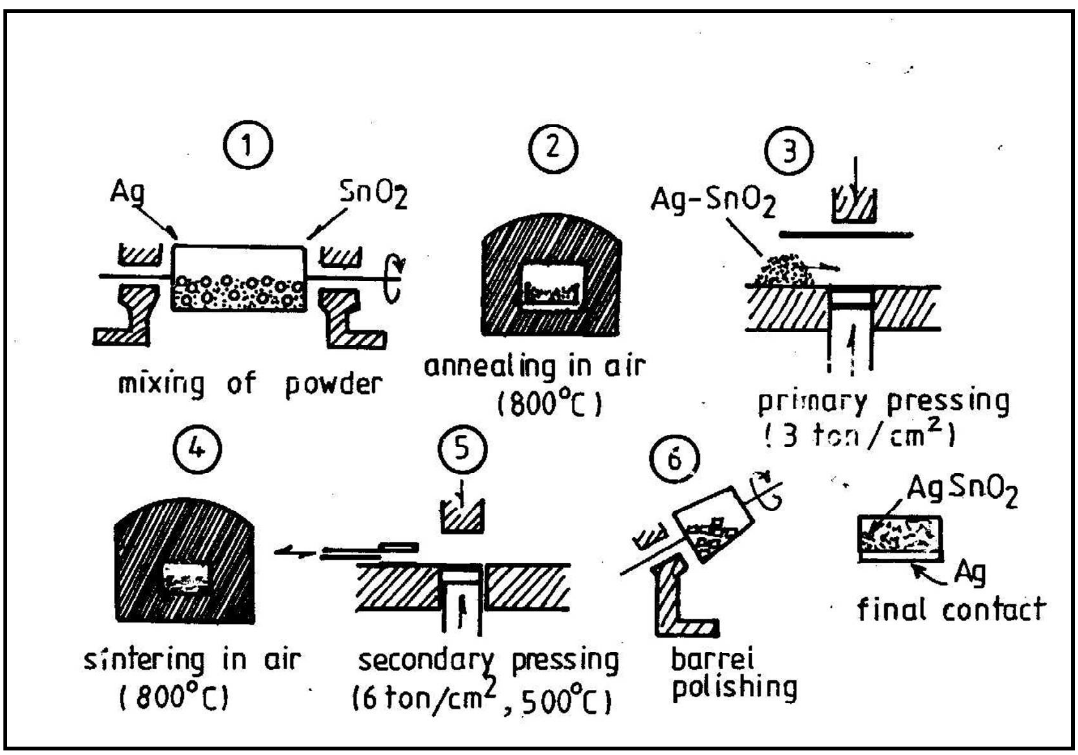
But there are issues pertaining to

- Alignment of the tubes
- Uniform distribution in the metal matrix
- Chirality of the tubes

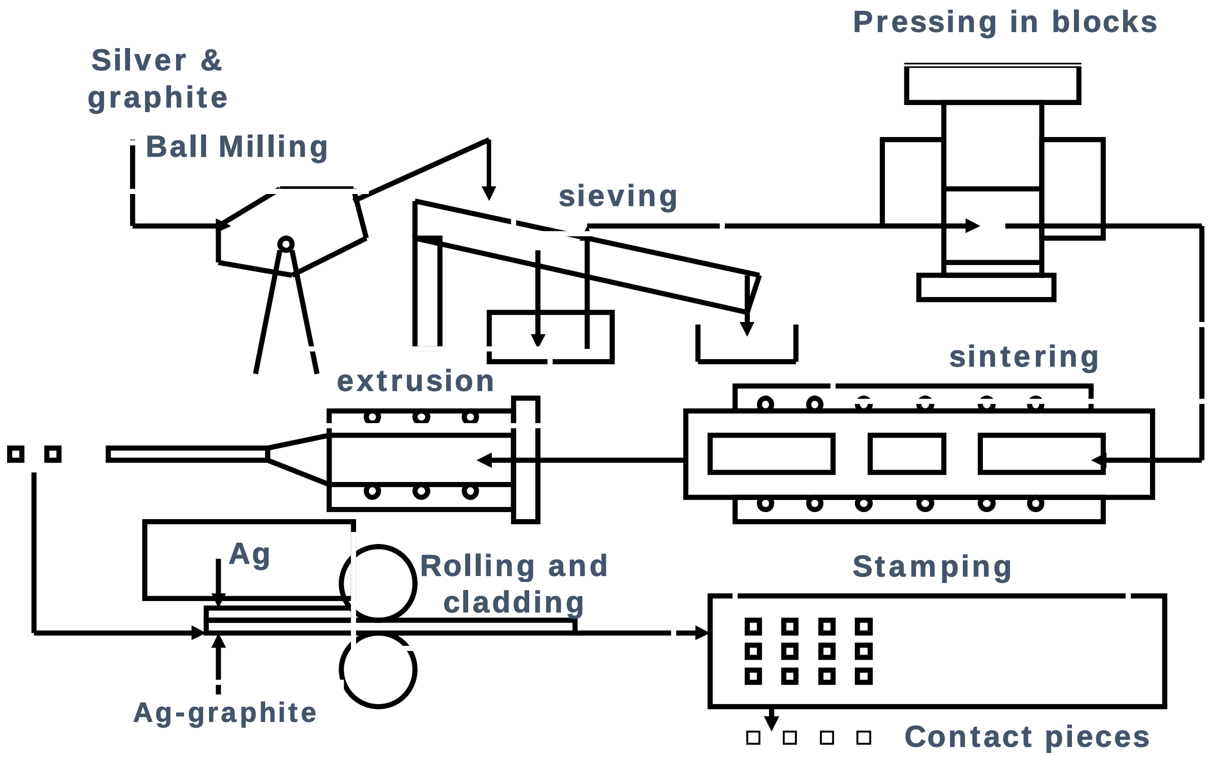
Powder Metallurgy (P / M) Process:



Schematic of press-sinter-repress route for Ag-SnO_2 powders



Schematic of press-sinter-extrude route for Ag-C contact materials:



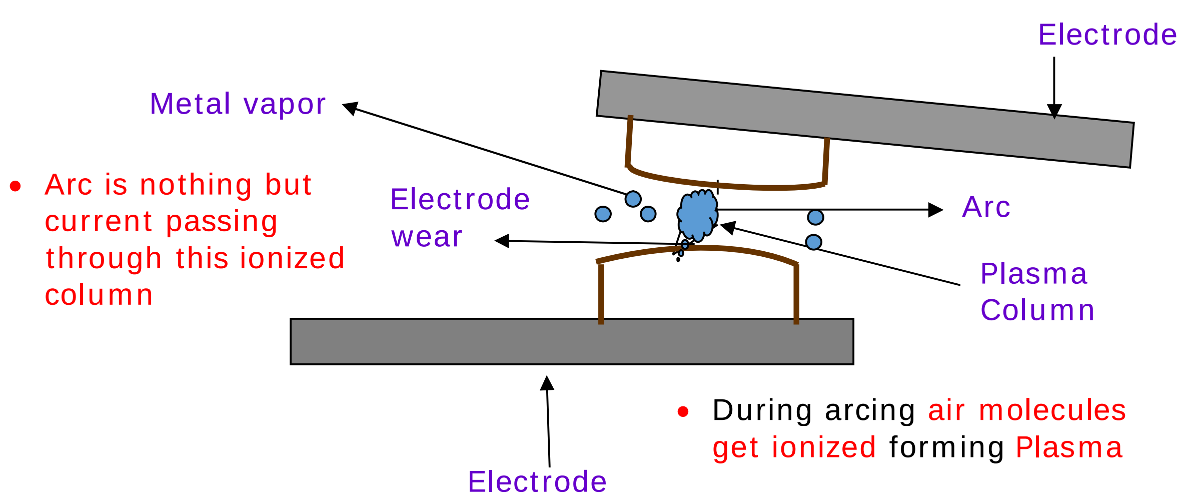
Failure Modes of Electrical Contacts

- **Erosion of contacts**
- **Welding of contacts**
- **Wear of contacts**

Failure due to contact erosion:

- Erosion of contact members occurs due to arcing while *making* and *breaking* of an electric circuit
- During every switching opera-tion a small amount of material is lost from the contact surface by way of evaporation and spla-shing from molten metal bridge.

Schematic of Arcing between a pair of Electrical Contacts

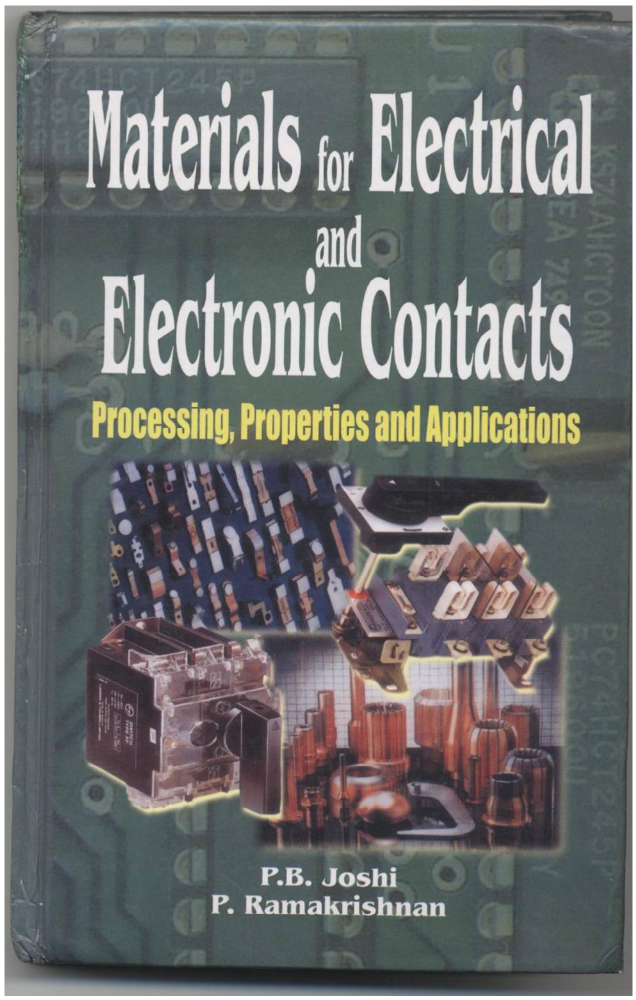


Failure due to wear of contacts:

- Wear is nothing but the loss of material by **gradual erosion of the contact members** during the course of their service.
- Contact wear is of two types namely,
  - Mechanical wear and
  - Electrical wear
- Arcing leads to electrical wear of contacts
- Damage due to mechanical wear is nominal compared to that due to electrical wear

Concluding remarks:

- Different contact systems used as make-and-break contacts or sliding contacts belong to a broad spectrum of materials ranging from pure metals and alloys to various composites.
- There is no set formula that dictates the ideal material to be used in a certain application.
- No single metal can cater to wide range of contact applications in switchgear devices, and hence a variety of materials have been developed as the electrical contact materials; each having its own merits & demerits



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FAILURE ANALYSIS OF COMPONENTS USED FOR POWER SECTOR APPLICATIONS

Dr. Vilas Gunjal and Dr. Uday Puntambekar
Electrical Research & Development Association (ERDA)

1. Introduction

There is a substantial increment in installed generation capacity in India to meet the increased demand of electricity. The generation plants and utilities strive to operate at higher efficiency to meet the supply requirements of consumer.

However, failure of components at power generation plants and at transmission and distribution lines pose major concern in meeting the demands. The component failures lead to plant shut-down, repair and replacement which cause tremendous cost to utilities. In this regards, analysis of failure is essential tool to avoid or delay the failure.

Failures in the form "Fracture" are considered to be the most serious failures and are given immediate attention. However, distortions, corrosion and erosion are also important, and sometimes lead to fracture.

The failure analysis is a cross-disciplinary activity which cuts across the entire gamut of the engineering and mathematical sciences. Further, once the cause of the failure has been determined, it immediately becomes possible to identify and formulate remedial strategies to ensure prevention of similar failures in future.

In this paper, overview on failure analysis methodology is presented

Apart from this, various failure types commonly observed in power sector across generation plants and transmission utilities are also discussed.

2. Classification of Failures

Failures are characterized either on the basis of the types of "failures modes" or the type of "service conditions" in which failures has taken place. The failure mode based characterization takes into account classical modes of material failure in different conditions, while the service condition based characterization of failures considers only the type of environment the component has experienced before failure. The failure of engineering component mostly occurs in two mode based on nature of failure: instantaneous loading failure and progressive failure as shown in Figure 1.

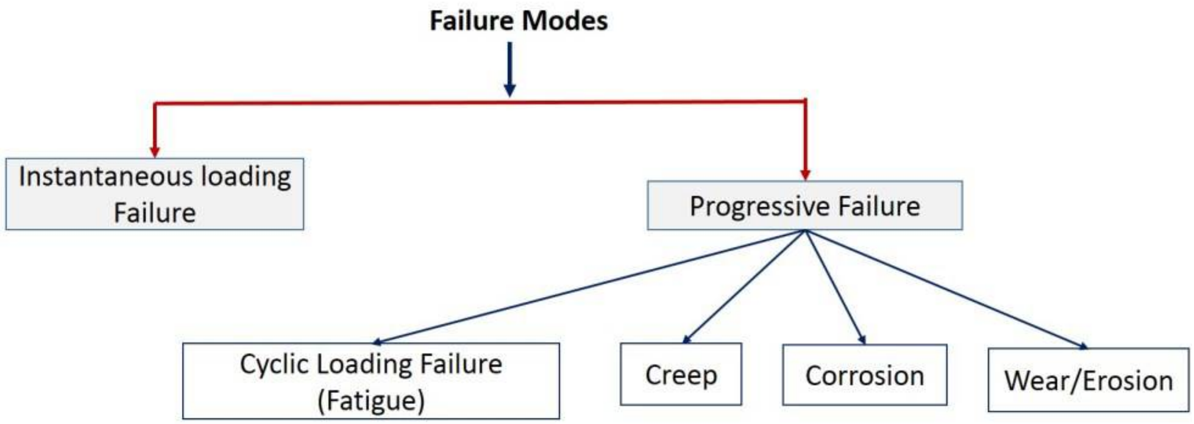


Figure 1. Various failure modes observed in engineering components

3. Failure Analysis Methodology

Failure analysis involves a systematic approach to identify possible causes and utilizes analytical techniques to pinpoint the exact cause(s). A failure investigation should determine the cause of a failure and based on that corrective action should be initiated to prevent the similar failures in future. A complex investigation usually requires the services of experts in several branches of engineering and the physical sciences. A four-phase approach generally followed for failure analysis is as below:

I) First phase –

a) Obtaining an overview of the failure.
b) Collection of background data /history and selection of samples.
c) Review of design specifications

II) Second phase –

Detailed investigation which typically includes-

a) Fractography (Optical & SEM)
b) Material Composition Analysis (Conventional / EDAX /XRD)
c) Macro & Microscopic examination
d) Mechanical & Physical Property Evaluation

III) Third phase –

Advanced analysis, including

a) Stress Analysis / Fracture Mechanics
b) Testing Under Simulated Service Conditions
c) Reliability Analysis

IV) Fourth phase –

a) Synthesis of Results of Investigation
b) Formulation of Conclusions
c) Recommendations / Remedial Measures

4. Failures of Components Observed in Power Sector

The commonly observed failures of components in power sector (generation plants and transmission lines) are discussed below;

Failures at Power Generation Plants

Premature failure of boiler tubes located in various zones such as water walls, super-heater, reheater, economizer, condenser etc. is one of the common phenomena observed in the power generation plants.

These tubes mostly have finite life because of prolonged exposure at elevated temperature, stress and aggressive environments.

Other critical components commonly found failed at power plant includes turbine blades, shafts and other structured components such as bearings, bolts and flanges etc. The major failure mechanisms responsible for the rupture of these components are creep, fatigue, erosion and corrosion. Fig.2 shows the schematic representation of component failure mechanisms observed at generation plants.

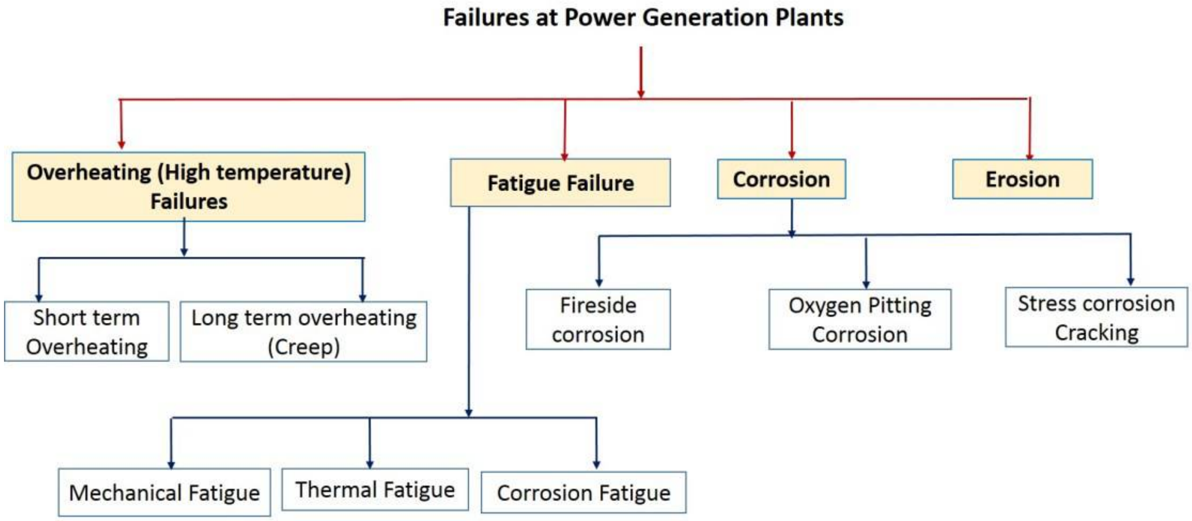


Figure 2. Schematic representation of failures types observed in power generation plants

4.1.1 High Temperature Failures

The exposure of boiler tubes above the design temperature results in overheating. The rise in temperature above design temperature can occur because of multiple factors such as increase in heat flux, internal deposit build up, reduced steam flow, non-uniform steam flow and improper burner adjustments etc. There are mainly two mechanisms associated with boiler tube overheating failure; 1) Short term overheating and 2) Long term overheating.

1) Short term overheating

Short-term overheating occurs when boiler tube is heated most probably locally to well above design temperature of the tubing material. This failure is also termed as thin lip rupture due to its appearance as shown in Fig.3. Thin lip rupture is a characteristic of stress rupture failure that is initiated by localized bulging and excessive tube wall thinning. The exposure of tube at very high temperature results in decrease in strength. Then, rupture of tube occurs when the stress on the tube wall (Hoop stress) is higher than material strength at that high temperature.

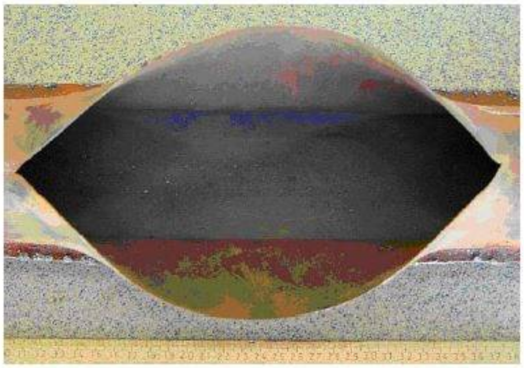


Fig-3. Boiler tube failure due to Short term overheating (1)

2) Long term overheating (Creep failure)

Time dependent deformation of component due to prolonged exposure at higher temperature and stress is known as creep. At high temperature, softening phenomena which are controlled by diffusion phenomena such as dislocation climb, dislocation annihilations, grain boundary diffusion and sliding, structural degradation such as spheroi-dization, primarily dominates the deformation and rupture behavior of material. In comparison to short term overheating, creep failure (long term overheating rupture) usually takes a much longer time in the order of five to twenty years because the temperature of boiler tube is slightly above the design. Long-term overheating damage usually occur with a small amount of creep deformation and results in thick lip rupture appearance as shown in Fig.-4.

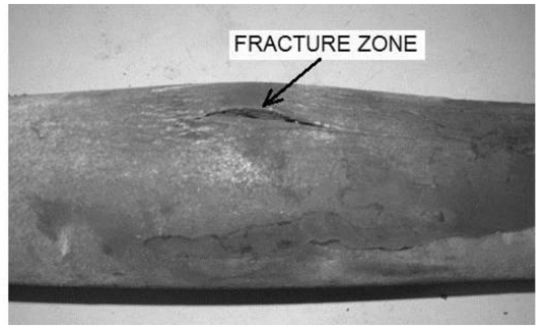
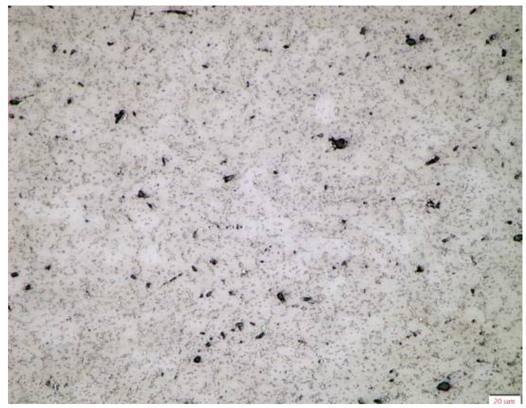


Fig-4. Boiler tube creep failure due to long term overheating (2)



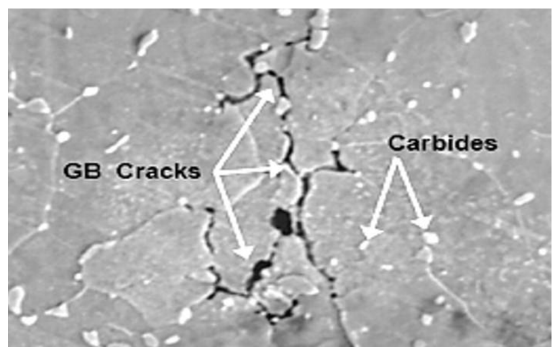


Fig-5. Microstructures of long term overheating failed tube (a) Optical micrograph; (b) SEM micrograph indicating presence of significant spheroidization and void formation during failure (3)

4.1.2 Fatigue Failure

Fatigue failure of engineering components and structures occurs through progressive damage due to presence of fluctuating cyclic stresses. Although, fatigue is progressive damage over time, the final fracture occurs instantaneously without any prior indication. The fatigue fracture occurs in three steps: crack initiation, propagation and final fracture. The cracks mostly initiate at the surface due to fluctuating loading and unloading. Then propagates inside the material forming striations, beach marks and finally fracture occurs when material's load bearing capacity decreases below critical stress limit. Figure 6 shows the fracture appearance of fatigue failure indicating characteristic features of fatigue such as ratchet marks (crack initiation sites), beach marks, striations in propagation zone and final smooth/fibrous fracture zone.

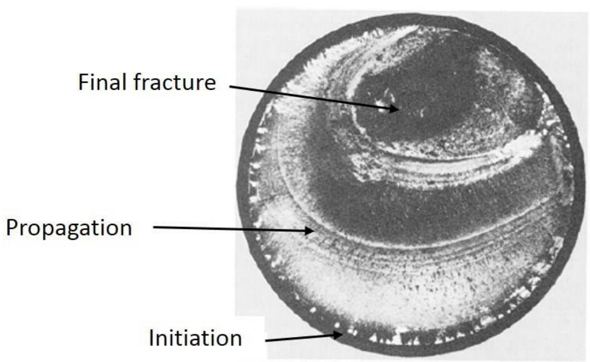


Fig-6. Fatigue fracture characterristics: Initiation, Propagation and Final fracture zones (4)

4.1.3 Corrosion Failures

Corrosion of boiler tubes on external wall surface and internal wall surface is one of the reasons for failure. Various corrosion mechanisms such as fireside corrosion (ash corrosion), flue gas corrosion, oxygen pitting corrosion, caustic corrosion, stress corrosion cracking (Sulphur, chloride environment) are observed in boiler components. Corrosion sites can act as a crack initiation sites for stress assisted cracking of boiler tubes.

i) Fireside corrosion:

Fireside corrosion of super-heater, re-heater and water wall tubes is high temperature corrosion in fossil fuel combustion boilers. It is mainly caused due to presence of Sulphur, alkali metals and chlorine in the coal, oil or natural gas. During combustion of fuel sodium sulphate and oxides (such as V_2O_5) are formed which are known as ash deposits. These low melting point deposits formed on the surface of super-heater and Re-heater tubes dissolve metal protective oxide layer on the fire side of a tube which is known as fire side corrosion of tube.

Fig-7. Photograph of super-heater tube surface with thick deposits due to corrosion (5)

ii) Oxygen pitting corrosion:

The pitting corrosion at internal wall of boiler tube mostly occurs due to dissolved oxygen in water. The localized corrosion pits formation (Fig-8a) occurs when protective layer (magnetite/Cr oxide) breaks down at internal wall surface. These pits acts as a fatigue crack initiation sites (Fig. 8b) and are responsible for corrosion fatigue/stress assisted corrosion failure.

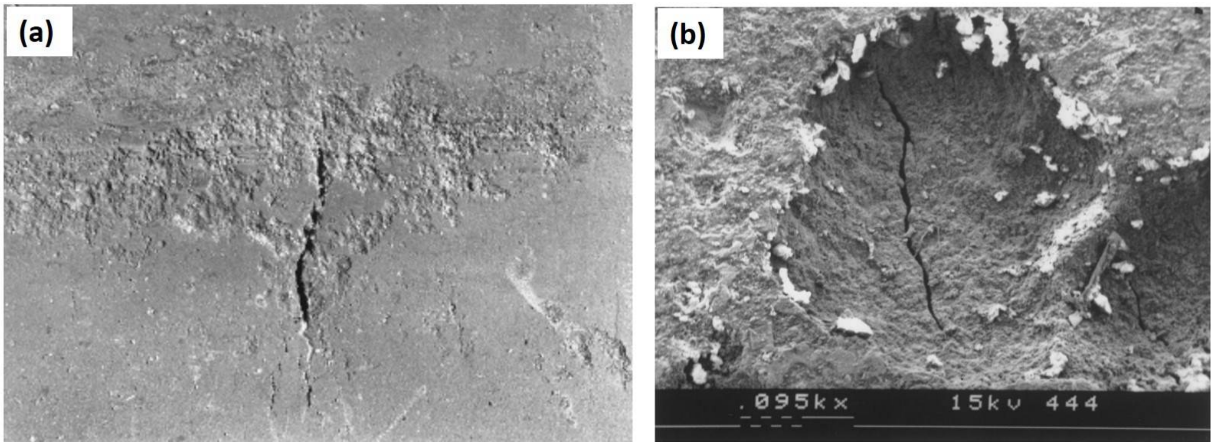


Fig-8. (a) Photographs of oxygen pitting (b) SEM micrograph indicating fatigue crack initiated at the bottom of pit (6)

iii) Caustic Corrosion:

The caustic corrosion of tube surface is the thinning of tube caused by caustic soda attack. It results in irregular deposit of whitish sodium carbonate (residue of caustic soda reacting with carbon dioxide in air). Solid deposits from water such as calcium and magnesium salts, silica, manganese and iron can form scale in a boiler. Under these scales, sodium salts are trapped which cause corrosion and remain unseen until you remove the scales. The caustic treatment is commonly used to prevent failures of hydrogen damage and acid phosphate corrosion. In case of improper monitoring and control of boiler water pH, excessive amount of NaOH in boiler water can result in inevitable caustic gauging (7, 8).

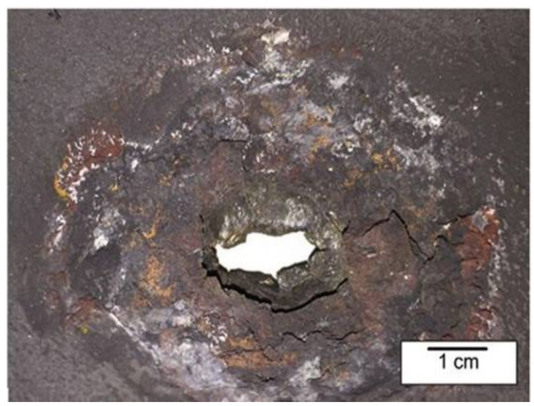


Fig-9. Caustic corrosion failure of tube. It shows white color deposits near the rupture (9)

iv) Stress corrosion cracking:

Stress corrosion cracking (SCC) commonly observed in stainless steels is the failure in presence of stress and corrosive environment. In case of austenitic stainless, sensitization (Prolonged heating of in ~415-810^{o}C sensitization temperature regime) results in chromium depletion in the vicinity of carbides precipitation at grain boundaries making it susceptible on cracking (Fig-10a). The failed component exhibit brittle, thick edged failures without any significant deformation. The crack propagation in SCC leads to branching as shown in Fig-10b. The stresses responsible for cracking can be thermal stresses due to restraint, hoop stress due to water/steam pressure, residual welding stress etc.

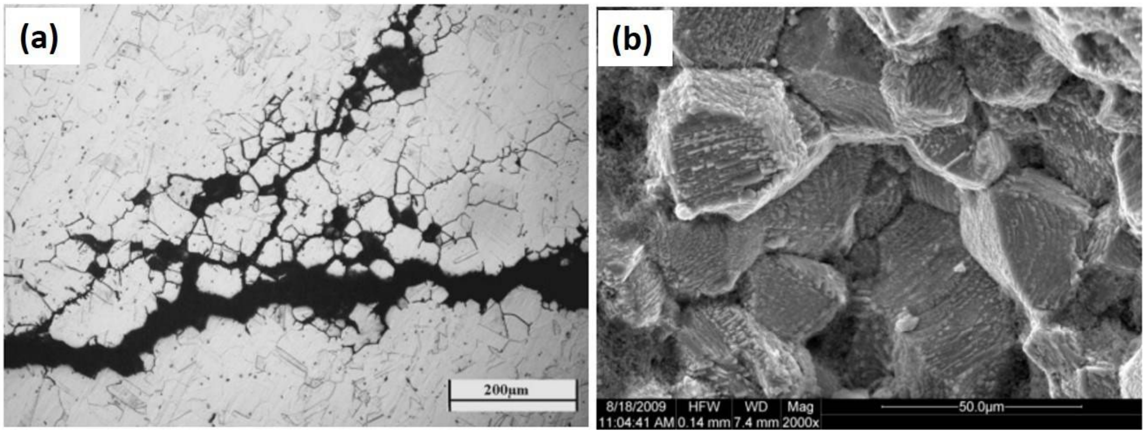


Fig-10. Microstructure of SCC (a) Optical micrograph (b) SEM micrograph of fracture surface indicating intergranular cracking (10)

4.1.4 Erosion

The erosion is a wear failure of tube which results in thinning of tube by material removal by the action of solid particles impinging on it. The combustion products of coal contain fly ash particles, soot Blow, which impinge on boiler tubes and erode them. Figure 11 shows the tube failure due to erosion. It indicates significant thinning of external wall surface due to erosion. The reduction in strength of material due to thinning causes rupture of tube.

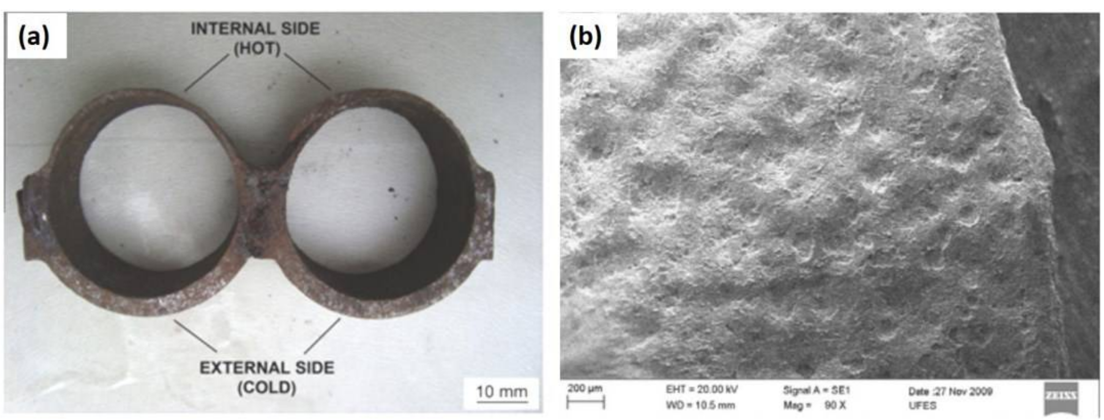
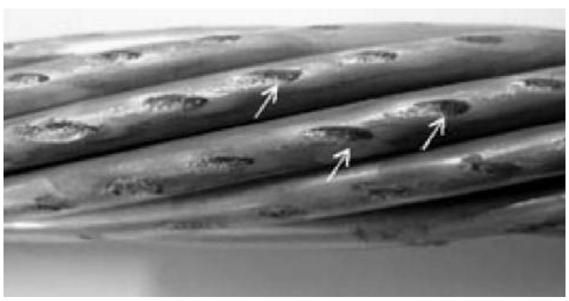


Fig-11. Erosion Failure (a) Photograph of boiler tube indicating erosion on fire side surface (b) SEM micrograph of eroded surface (11)

4.2 Failures at transmission and distribution utilities

Overhead transmission lines conductors carry electrical energy from generating stations to distribution stations and to consumer. These are bare conductors above the ground levels, supported between two towers and susceptible to failure due to extreme environmental conditions such as heavy wind in forest and hill areas, humid and corrosive coastal regions etc. The most deteriorating problems in conductors are mechanical fatigue and corrosion of conductor wires.

The fatigue failure of conductor strand mostly occurs due to aeolian vibration and wear, especially at devices such as spacers, clamps etc. which restrain its movements. The aeolian vibrations results in bending stress and clamping torque on the conductor to initiate the fatigue. The fatigue crack initiation mostly occurs due to fretting/wear near the contact and finally fails typically at 45° as shown in Fig-12.



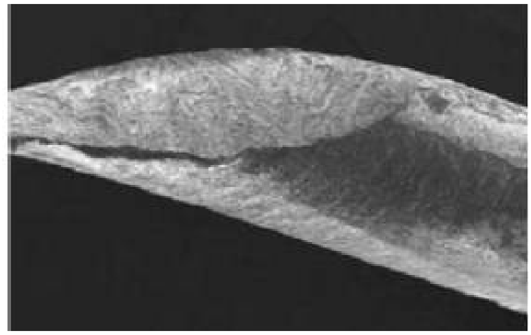


Fig-12. Photographs of fatigue failure of ACSR conductor. (a) Fretting marks on strands near clamp area; (b) failed strand indicating fracture at 45° (12)

The environmental factors such, as industrial pollution, marine salts, humidity in the air etc. are the reasons for corrosion of conductor strands. In case of ACSR conductors damage of preventive coatings (zinc coating) of steel core results in galvanic corrosion, making aluminum wires anodic, leading to aluminum strand failure. (Ref. Fig. 13)

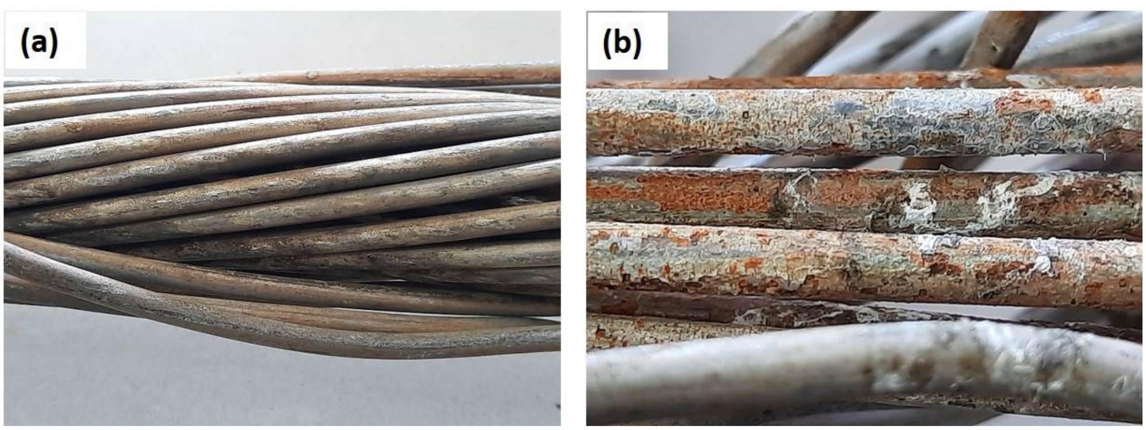


Fig-13. Photographs of ACSR conductor indicating corrosion of strands (a) Aluminum strands (b) steel strands

5. Closure

Failure Analysis is a systematic study involving various tools & techniques such as material characterization, design, fracture mechanics, etc. The science and technology of failure analysis are now well developed. Documented procedures / guidelines are available in various reference handbooks. It is suggested that the industry should make use of failure investigation not only for avoiding repetitive failures but also for gaining crucial inputs for their product development / improvement cycle.

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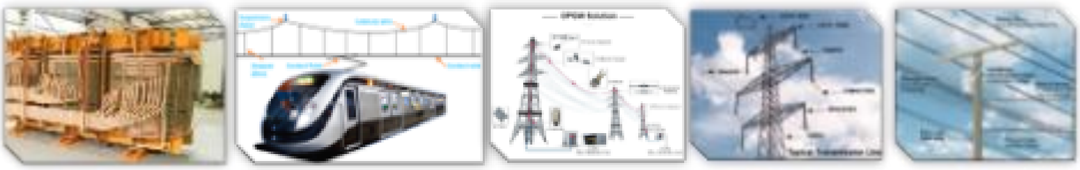

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