

**Residual life assessment of 40TPH CFBC Boiler through different Non-destructive testing Techniques in Thermal Power Station.**V.H.Patil¹, Dr. C.R.Patil²¹Associate Professor, Dept. of Mechanical Engineering, GF's Godavari College of Engineering, Jalgaon, MS India 425002²Professor, Department of Mechanical Engineering, PRMITR Badnera, MS India 444701

Abstract: -This Paper endorses an overview of nondestructive test (NDT) carried out for remaining life assessment of 40 TPH (CFBC) boiler. A failure in any part of boiler ultimately affects the shutdown of plants and affects on power generation which leads to heavy losses. The NDT plays a key role in boiler maintenance and its prevention from failure and preventive maintenance of boilers aids in finding out various metal fractures, swallowing of metal tubes, metal removal due to corrosion and erosion, fractures due to fatigue failure can also be noticed in the early stages. In this paper different non-destructive test carried out such as visual inspection, dimension measurement, Ultrasonic test based on available plant data and this results of residual life assessment provide not only a basis for further maintenance, but also estimated time for reparation or renewal. Ultimately it reduces cost of power plant.

Keywords: - NDT, Remaining life assessment, CFBC Boiler

1. INTRODUCTION

Evaluation of remaining life time of thermal power plant boiler gives us possibility for optimization of plant maintenance schedule and boiler revitalization. There are different methods for calculations of material exhaustion degree caused by creep and fatigue; most of the methods are described by relevant technical standard and norms. Boilers and other installations operating at high pressures and temperatures are designed for a finite life. The design life of a boiler often is not openly specified. Many designers and specialists consider 25 to 30 years to be a reasonable estimate for the life of water tube boilers and for the power plants of which they are part. [1] In thermal power plant boiler is one of the most critical equipment, so its reliability and safety is most important issue. The major percentage of forced shutdown of power station is due to boiler maintenance so it is necessary to predict root causes of force out edges and remedial action to prevent the reoccurrence of similar failure in future. A boiler of thermal power plant typically consists of different high pressure parts like Bed coils, water wall tubes, superheater tubes, Reheater tubes and Economizer Tubes.

Thermal power plants around the world are aging and need to be assessed to ensure continued safe operation. Replacement is frequently not an option because of high capital costs, and the much lower cost of continuing the operation of the older plant. [2] The tremendous demand for the power in today's world is pushing the power generation industry to continue operating their existing aging units. As a result, the remaining life assessment of these aged units is becoming important for continued safe and reliable operation. Among the factors that determine the lifetime of boilers are the strength and reliability of components that are exposed to high temperatures and pressures. So, remaining life assessment of these components/materials is essential for the lifetime extension of these aged units through repair work, continuous inspection, replacement of the degraded parts, etc [3]

There are three levels involved in life assessment of components. Data from fracture, failure history, dimension condition, temperature and pressure, stress, material properties and material samples are used in three level approaches. If the Level I assessment indicates that the calculated remaining life is greater than or equal to desired life extension, then regular inspection and periodic review program should be proceeded. Otherwise Level II assessment should be followed. In the Level II assessment information from an initial inspection, simple stress analysis, measured dimensions or operating parameters are used. If the residual life arrived in the Level II is less than projected / expected extended life, then more precise evaluation Level III can be used, provided the values of the component exceeds the cost of detailed evaluation. [4] Nondestructive testing, Risk based inspection, reliability engineering these are the methodology used for residual life assessment. The main objective of this systematic approach of inspection of old power plant are to

- Enhance the operating life of boiler.
- Increase the safe operational reliability for extended life.
- Improved boiler availability.
- Prevents catastrophic failures of pressure parts.
- Prevents forced outages and repairs.

This study focuses on the use of different Nondestructive technique and implementation of such procedure carried out in Thermal power plant. This decision of implementation is depending on power plant characteristics, service conditions and Plant owner.

2. Requirement of Residual Life Assessment (RLA) Study

For the boilers which operates more than the creep temp 400°C , carrying out RLA study is mandatory after 1, 00,000hrs. of operation. (after about 11.4 years of operation). For the boilers which operate less the creep temperature, carrying out RLA study is mandatory after 25 years. But for above mentioned boilers the RLA study has to be repeated after every 5 years of operation as per act for boiler health & safety.

3. Residual Life Assessment

Equipment's are designed to work under certain conditions and has certain expected life. If this equipment's are operated under harsher conditions, then their useful life is short. For the estimation of the residual lifetime the maximum expected lifetime, assuming that the equipment will be operated under same conditions, has to be found out. The expected lifetime is a function of the operating conditions. In dependence of the average load level it can get shorter for higher load conditions. The residual lifetime can be defined as the difference between the expected lifetime and the actual age. For general mechanical equipment the relationship between expected life and load conditions can be described as (Figure1) [5]

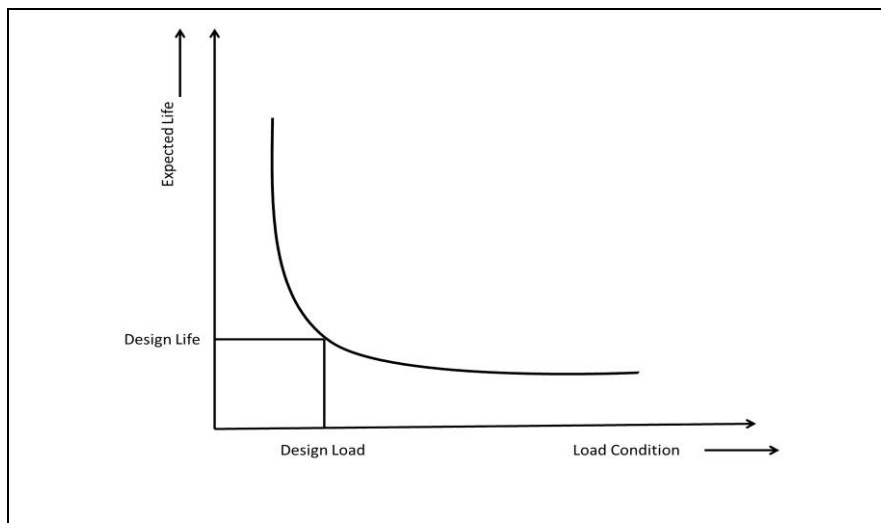


Fig. 1. Relation between expected life and Load

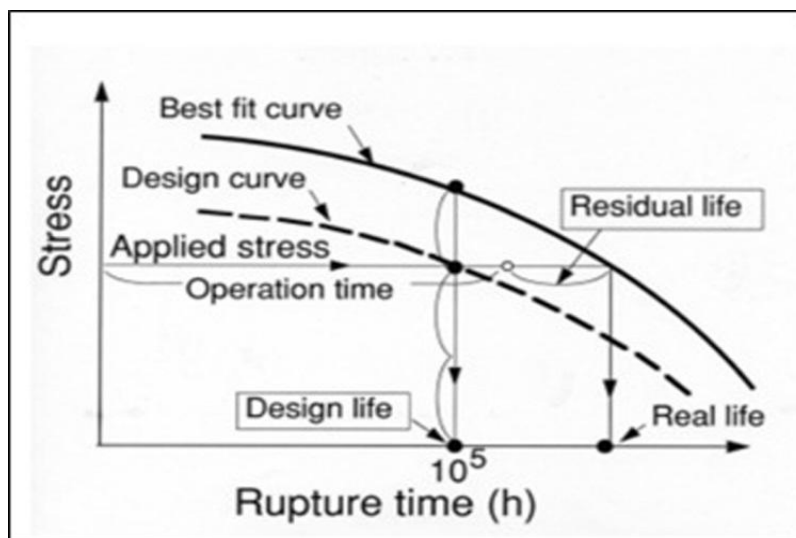


Fig. 2. Difference between Design life evaluation and residual life

The above figure shows difference between the life evaluation at the design stage of a boiler plant and residual life assessment of the plant. The life assessment at the design stage is based on a design diagram which is obtained by multiplying the average life of materials employed in the plant by safety factors. The remaining life assessment is to seek the time that the materials reach their actual life in operation [6].

The main objectives of RLA should be as follows.

1. Establishing of NDT technique.
2. Establishing method for planning the requirement of long lead items based on RLA.
3. Selection of stream for shutdown purpose based on RLA.
4. Prediction of impending failures of critical plant components resulting in enhanced safety, operational reliability, availability, and maintainability.
5. Establishing life prediction approach to enable repair, upgradation, replacement of necessary components and extension of remaining components life [7]

Methods of Residual life assessment are dependent upon a multiplicity of factors. The Residual life assessment depends upon material properties, usage history, and the damage intrinsic to the material component itself. Knowledge of the geometry and location of the flaw and their interaction, if any, allows determination of component life. [7] Life assessments are needed to avoid unexpected component failure and premature replacement of components prior to the end of useful life. It is clear that residual life assessment is essential to avoid unnecessary failure of component. It directly affects the cost and time [8]

Life assessment methodology can broadly be classified into three levels. Level 1 methodology is generally employed when service life of the components is less than 80% of their design lives. In level 1, assessments are performed using plant records, design stress and temperatures, and minimum values of material properties from literature. When service life exceeds 80% of the design life, Level 2 methodology is employed. It involves actual measurements of dimensions and temperatures, stress calculations and inspections coupled with the use of the minimum material properties from literature. However, when life extension begins after attaining design life, Level 3 methodology is employed. It involves in-depth inspection, stress analysis, plant monitoring and generation of actual material data from samples removed from the component. The details and accuracy of the results increase from level 1 to level 3 but at the same time the cost of life assessment increases. Depending on the extent of information available and the results obtained, the analysis may stop at any level or proceed to the next level as necessary. [9]

Remaining life assessment technique would depend on the nature of damage or defects that may have accumulated during service. Careful non-destructive evaluation is always the first step in any integrity evaluation activity. Modern non-destructive tools can not only detect fine defects/cracks but also provide an estimate of material properties. The defect size determines the approach which would be most applicable [10]

4. Non-Destructive Testing

Nondestructive test do not measure the mechanical properties such as tensile strength or hardness, but they are used to locate the defects or flaws in the component. The equipment which undergoes RLA studies, is completely dismantled and each and every part is inspected for damage and wear out. The parts which are critical for proper operation of the equipment are inspected thoroughly using various Non Destructive Evaluation Techniques.

They are –

1. Nondestructive examination (NDE) technique e.g., dimensional measurement, optical observation, and ultrasonic, eddy current, X-ray.
2. Metallographic examination, e.g. through-section, outer surface, and plastic replication techniques.
3. Risk-based inspections (RBI). [5]

Non-destructive testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. The terms Nondestructive examination (NDE), Nondestructive inspection (NDI), and Nondestructive evaluation (NDE) are also commonly used to describe this technology. Common NDT methods include ultrasonic testing, magnetic-particle inspection, liquid penetrant testing, remote visual inspection (RVI), eddy current testing. [5]

NDT inspection of industrial equipment and engineering structures is important in power generation plants, petroleum and chemical processing industries, and transportation sector. State-of the-art methodology is applied to assess the current condition, fitness-for-service, and remaining life of equipment. NDT inspection provides basic data helping to develop strategic plans for extending plant life. NDT life extension and life assessment services include

- Equipment integrity analysis.
- Corrosion monitoring of structures and equipment.

- Corrosion damage evaluation.
- Fatigue and creep damage prediction.
- Fitness-for-service evaluation. [11]

The NDT is an interdisciplinary field dealing with non-invasive inspection of component and product structure and integrity. It plays a critical role in assuring that structural components and systems perform their function in a reliable and cost effective fashion. NDT methods aim to locate and characterize material conditions and flaws that might otherwise cause planes to crash, reactors to fail, trains to derail, pipelines to burst, and a variety of less visible, but equally troubling events. These tests are performed in a manner that does not affect the future usefulness of the object or material. [11]

The choice of NDE technique to be employed would depend on material toughness. Lower the toughness, shorter is the critical crack length. Such material would therefore demand for more sensitive equipment to be employed. Past experiences reveal that prolonged service exposure leads to embrittlement or loss of toughness. Therefore old/ageing components are required to be evaluated more carefully. [10]

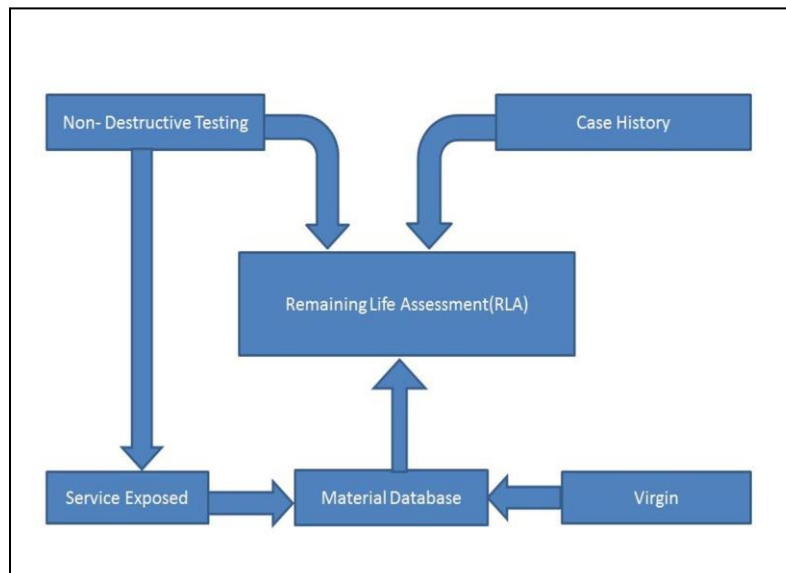


Fig. 3. Role of non-destructive testing in remaining life assessment

The remaining life assessment of thermal power plant is mainly related to remaining life of boiler and material condition which are used for boiler and its components. The above figure shows relations of life assessment of components is mainly related to nondestructive technique which based on service exposed, material database and previous data available of plant. This database gives indication about different NDT to be carried out for component of thermal power plant.

Conventional methods such as penetrant testing (PT) and magnetic particle testing (MT) are well suited to detect surface and slightly subsurface discontinuities. These methods are particularly sensitive to small surface service induced cracking in various components. Penetrant testing, which requires the discontinuity to be open to the surface for detection and magnetic particle testing can only be used on magnetic materials. Visual inspection (VT), performed either with the human eye or with high-resolution cameras, is limited to dimensional measurements, usually the detection of large open discontinuities or component condition assessment. Longitudinal and shear wave ultrasonic testing (UT) is used for full volumetric interrogation of a component while eddy current testing (ET), an electromagnetic method, is sensitive to small surface or slightly subsurface indications in many materials. Radiography testing (RT), using X-rays or gamma rays is useful for detecting internal indications in welds, pipes, and a host of other components. [3]

5. Procedure for NDT of 40 TPH CFBC Boilers

Nondestructive tests for 40 TPH AFBC boiler of thermals power plant are selected from available data of inspection and material conditions, also discussion with plant manager and quality head. Following table 1 shows boiler details on which different NDT is to be carried out

Table 1
 Details of Boiler

sr. no.	Description	Original thickness
1	Make Type	CVL
2	Type	CFBC
3	Working Pressure	44 Kg/cm ²
4	Working Temperature	410 + 10 ⁰ C
5	Capacity	40 TPH

Different NDT selected to be carried out on Boiler components as follows: -

Table 2

Different NDT selected

sr. no.	Description	Test Selected to Conduct					
		VI	DM	LPT	UT	IM	FI
1	Steam drum	Yes	Yes	Yes	Yes	Yes	Yes
2	Mud drum	Yes	Yes	Yes	Yes	Yes	Yes
3	Convection super heater headers	Yes	Yes	Yes	No	Yes	Yes
4	Bed superheater headers (I/L & O/L)	Yes	Yes	Yes	Yes	Yes	Yes
5	Bed evaporator header (I/L & O/L)	Yes	Yes	Yes	No	Yes	Yes
6	Economizer headers (I/L & O/L)	Yes	Yes	Yes	No	Yes	Yes
7	Furnace header	Yes	Yes	Yes	No	Yes	Yes
8	Main steam line	Yes	Yes	Yes	Yes	Yes	No

VI - Visual Inspection

LPT - Liquid Penetrant Test

IM - In Situ Metallography/ replica

DM - Dimension Measurement

UT - Ultrasonic Test

FI - Fibroscopy/ Videoscopy

5.1. Visual Inspection: -

Visual inspection reveals the surface defects and any abnormality in shape and size of components. Presence of cracks on surface and surface roughness can be checked by moving figures over the component surface [13]. Visual examination is carried out to assess material wastage due to oxidation, erosion/corrosion problems, fouling conditions of heat transfer surfaces, integrity of attachments in coils specially for surface roughness. This includes inspection of drum internals to ensure proper steam/water separation. During visual inspection the observations made with reference to discoloration of coils, misalignment is considered in deciding sample tubes removal for metallurgical examination and corrosion. Prior evaluation of pressure part condition, based on experience and design knowledge from similar plants sample is selected. Following figure shows corroded insulated tubes & headers due to aging of insulation during visual examination. Similarly, samples from the regions thus determined to be most susceptible to failures and samples depicting the general condition of each component are selected for an evaluation of the metallurgical condition.



Fig. 4. Corrosion of Tube during Visual Inspection

5.2.Dimension Measurement: -

Dimensional measurements carried out to determine swelling (bulging) outside diameter, thickness measured with the help of Micrometer, Vernier caliper, outside caliper etc. and sometimes low power magnifying glasses with artificial illumination may be used. Results obtained from dimensional measurement are tabulated in the following table 3

Table 3

Dimensional Measurement result table

. sr. no.	Description	Original thickness	Actual thickness
1	Steam drum	ID 1340 x 63 Thk	ID 1350 x 65 Thk
2	Mud drum	ID 950 x 56 Thk	ID 980 x 59 Thk
3	Convection super heater headers	OD 168.3 x 10.9 Thk	OD 170.5 x 9.5
4	Bed superheater headers (I/L & O/L)	OD 219 X 20 Thk	OD 218 x 18.8 Thk
5	Bed evaporater header (I/L & O/L)	OD 219 X 20 Thk	OD 217 x 16 Thk
6	Economizer headers (I/L & O/L)	OD 219 x 20 Thk	OD 217 x 16.5 Thk
7	Furnace header	OD 273 x 20 Thk	OD 274 x 19 Thk
8	Main steam line	OD 273 X20 Thk	OD 273 x 16 Thk

5.3. Liquid Penetrant Test: -

Invisible cracks, porosity and other defects on surface of components can be easily detected by using this test. The dye penetrant is allowed to penetrate in the surfaces flaws. Depending upon the type of defect, time may be anywhere between few seconds to several hours.[14]

In this test liquid (dye) penetrant is applied to the surface which is clean and dried to be examined and allowed to enter into the discontinuities. All excess penetrant from surface is then removed by soft and clean cotton after that surface is dried and the developer applied. The developer serves both as a blotter to absorb the penetrant coming out by capillary action and as contrasting background to enhance the visibility of the indication. Following figure shows developers are applied on parts to be inspected along with dye coming out from flaws and cracks, pinholes, pitting and other weld defects.



Fig. 5. Liquid penetrant Inspection

5.4 Ultrasonic Test: - Ultrasonic testing is a very fast method of testing for defects because the time travel of ultrasonic waves is order of microseconds for the usual size of the component. In ultrasonic test involves measure of time require by ultrasonic waves to penetrate material and behavior of these waves recorded on cathode ray oscilloscope screen. [13] High frequency sound waves applied to the surfaces and sub-surfaces selected for ultrasonic test. The variations of wave's patterns detected on CRO screen and by visual observations presence of flaws, cracks, laminations, shrinkages, cavities, flakes, pores and binding faults was located. Following figure [5] shows ultrasonic test is applied to long seam and circum seam of steam drum. This technique also used for measuring oxide scale thickness of high temperature tube. The thickness for tube should not below 3 mm as per IBR act which is to be compared with original thickness of components.



Fig. 6. UT of Steam Drum

Thickness survey report

Strength calculation for Tubes

$$W.P. = 2 f \frac{T - C}{D} - T + C \quad (1)$$

Where,

Wp = Working pressure, Kg / cm²

f = Allowable Stress, Kg / cm²

T = minimum thickness, mm

D = External diameter of tube, mm

C = 0.75

Metal temperature Furnace tubes 345 deg C

Sr. no	Description	Original Tube size ,mm		Min. thk required, mm	Material	Allowable stress f, Kg/cm ²	Working pressure, Wp , Kg/cm ²
			Thk				
1	Waterwall	60	5	2.8	SA210 Gr A1	1195	88

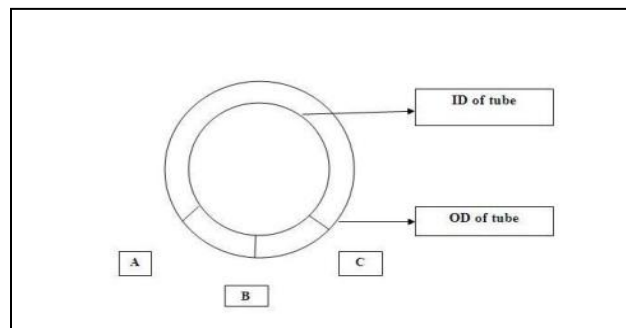


Fig. 7.Thickness measurement of tube

Thickness measurement of Front wall															
			< 3		3 to 4		4 to 4.5		4.5 to 5		5 to 5.5				
Tube no	100 mm from kickoff			400 mm from kickoff			700 mm from kickoff			1000 mm from kickoff			1300 mm from kickoff		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	5.5	5.4	5.6	5.4	5.6	5.5	5.2	5.2	5.4	5.7	5.5	5.8	5.2	5.4	5.2

5.5. Replica Test:-In this test, metal surface is polished by equipment and spot made free from rust using abrasive paper of varying grits from 120, 200, 400 and 600 in sequence. Later diamond paste lapping is done followed by etching with 3% nital to reveal the structure. Component microstructures surface is truly transferred to a film. Transparent film

with green reflecting foil is used which examined in laboratory with magnification up to 500X for the metallurgical damages like creep cavitation. In case of higher magnification, the microstructure of component is transferred to cellulose acetate replicating tape. A cellulose acetate film of 0.1 to 0.15mm thickness and 20 x 40 mm size is cut from roll or sheet.

A few drops of acetone are applied on one surface for about 5 seconds and acetate film soft on one side and retains hardness on the reverse side. The soft side is pressed uniformly over the etched surface using clean and plain rubber and exerting the force of the thumb for about 10 seconds. It is protected against dust and left for some time for drying. The dried film is lifted up by fine knife and kept between parallel glass slides. This film is used in micro structural examination using light optical microscope. The following figures (8,9) shows the microstructures i.e. ferrite and pearlite in Economizer header and Convection superheater header. Also table 5 shows microstructure features and remedies to be taken for components.

Table 5

Replica Test Result

sr. no.	Description	Microstructure features	Action needed
1	Convection super heater headers	oriented cavities	Replica Test Carried out at specified intervals i.e. after 2 years
2	Bed superheater headers (I/L & O/L)	Isolated cavities	None until major scheduled maintenance outage
3	Bed evaporator header (I/L & O/L)	Isolated cavities	None until major scheduled maintenance outage
4	Economizer headers (I/L & O/L)	ferrite & Perlite	None
5	Furnace header	ferrite & Perlite	None
6	Main steam line	Isolated cavities	None until major scheduled maintenance outage

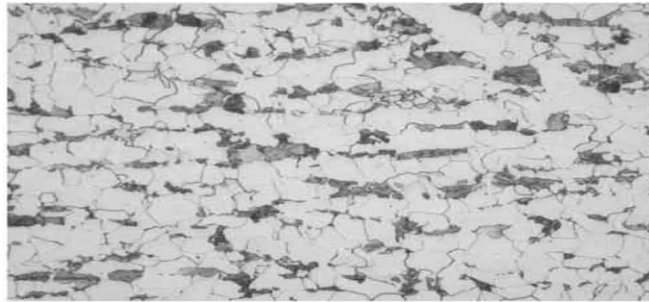


Fig. 8. Microstructure showing ferrite & pearlite in Economizer header



Fig. 9. Microstructure showing oriented cavities ferrite & pearlite in Convection superheater header

5.6 Fibroscopy/ Videoscopy: -

A flexible Fibro scope is used for internal inspection of components like headers, pipes, tubes etc. by illuminating and observing internal and inaccessible components. This inspection reveals the valuable information about the inside condition especially scale formation inside the components. Following figure shows views obtained by Videoscopy in bed evaporator which gives a scale formation inside component.



Fig. 10. Observation during Videoscopy foreign particles present in bed evaporator

6.1.

ResidualLife Calculation of CFBC Boiler: -

6.1.1. Using Damaged parameter: -

In high pressure and high temperature components, headers & steam pipes, the consequential damage mechanism is creep, which manifests itself in the form of cavities in the microstructure. The morphology (shape characteristics and orientation) of the cavities shows the status of the component in terms of its remaining life. The phenomenon of creep is guided by the factors such as temperature, stress, time and material properties. Given a material that is subjected to constant temperature and stress (pressure), creep damage evident in the microstructure will be a function of time (extended life fraction)

6.2. Fatigue Usage Fraction:-

The maximum stress developed due to thermal pressure. Take alternating stress range (S range), with the lower limit zero towards the max in the shutdown condition, fatigue life usage fraction is obtained from S-N curve as

$$Uf = \frac{n}{N} \quad (2)$$

Where, n is the actual number of stress cycles experienced by the component, and N is the maximum number of stress cycles that the component can withstand. [7]

6.3. S-N Curve: -

This curves represent the relationship between the stress range and corresponding fatigue life 'N' measured in terms of number of stress cycles to failure. To develop these curves, fatigue tests are conducted in laboratory on representative samples. For each stress range different values of number of cycles till failure are obtained. S-N curves have been developed based on data of full size specimen of different types of connections. Where stress range and N is number of stress cycles to failure.

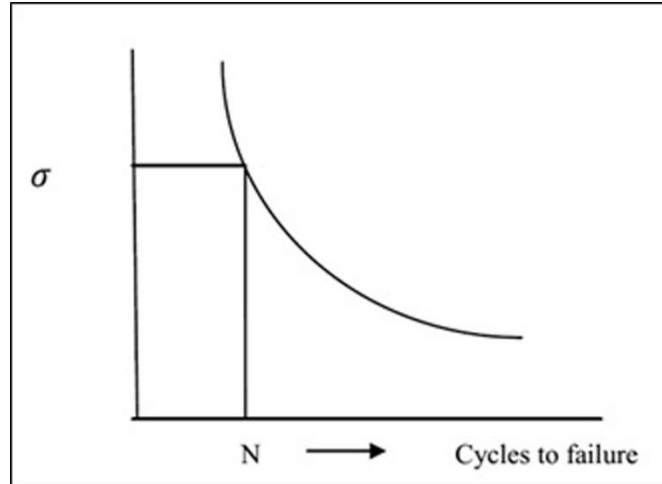


Fig. 11. Stress to number cycle graph

Creep Usage Fraction:- Maximum stress due to pressure and load condition, creep life usage fraction (U_c) is obtained from creep curve at operating temperature.

Creep life usage fraction is given by the ratio t/t_r .

Where t is total duration in hour and t_r total time from s - t curve. [2]

Residual Life Estimation:-Theoretically, residual life fraction of component is given by

$$RLF = 1 - U_f - U_c \quad (3)$$

However, due to many factors influencing fatigue and creep such as deviations from design during manufacture and operation, notches, surface finish, size of component and creep-fatigue interaction, which are not theoretically estimated

Residual Life Fraction is given by:-

$$RLF = \left(\frac{1}{2}\right) - U_f - U_c \quad (4)$$

The remaining life assessment will be done based on various the following methods:

6.3.1. Metallographic Analysis Method:-

In high pressure and high temperature components, headers & steam pipes pursue, the consequential damage mechanism is creep, which manifests itself in the form of cavities in the microstructure. The morphology (shape characteristics and orientation) of the cavities lends clue to the status of the component in terms of its remaining life. The conclusions drawn, however, are not deterministic. Nevertheless, the component susceptible to consequent failures could be identified and necessary action(s) could be initiated. The phenomenon of creep is guided by the factors such as temperature, stress, time and material properties. Given a material that is subjected to constant temperature and stress (pressure), creep damage evident in the microstructure will be a function of time (expended life fraction).

6.3.2. Accelerated uniaxial creep test method:-

A very common way of estimating the remaining life under creep conditions is the use of uniaxial creep test on the service exposed material. An approach commonly employed is to test a specimen from the service-exposed component to rupture under accelerated conditions in the laboratory. The iso-stress accelerated creep rupture test may be conducted at the chosen higher temperature for a duration of hours as per precalculation and if the test passes this duration without rupture the extension of life for the boiler can be recommended for calculated years .

7. CONCLUSION

Life Assessment of power plant components has gained significant importance in the past decade as the power plants have aged and newer technologies have become available for inspection and evaluation of these components because of increase in demand of electricity. In Residual life assessment, especially advanced Nondestructive techniques for power plant components inspection plays a vital role to evaluate the condition of plants and aids in the safe operation of plants. Additionally, these techniques provide information that assists in the lifetime assessment of power plant components.

Components in the power generating equipment are examined through appropriate nondestructive test and further analyses based on the results obtained from the NDE. These evaluations coupled with the operating history and material history of the components provide the basis for lifetime analyses. The NDT provides testing of components which is hard to test due to high pressure and high temperature exposure continuously which helps in increasing life of plant effectively by using reparation or repair according to condition of components.

Acknowledgements

The authors are grateful to the authorities of Bhusaval thermal power plant who allow to perform various test of boiler. The organization also provides various data required to carry out this work.

REFERENCES

- [1] Flavio A. Paoliello, Guidelines for integrity evaluation and remaining life assessment of recovery boilers- Cenibra's Experience, TAAPI Journal, Vol.4:No.2, February 2005; pp. 17-22.
- [2] Damir Hodžić and Ismar Hajro, PROPOSAL OF PROCEDURE FOR REMNANT LIFE-TIME EVALUATION OF BOILER COMPONENTS IN THERMAL POWER PLANTS, 16th International Research/Expert Conference", Trends in the Development of Machinery and Associated Technology" TMT 2012; Dubai, UAE, 10-12 September 2012, pp. 355-358.
- [3] Waheed Abbasi and Sazzadur Rahman, NDE Inspections and Lifetime Assessment of Turbine Equipment, Power-Gen International 2008 – Orlando, Florida, December 2-4, 2008; pp. 2-11.
- [4] Dr. P.U. PATHY, CONDITION ASSESSMENT OF BOILER AND Its COMPONENTS, 3rd MENDT - Middle East Nondestructive Testing Conference & Exhibition - 27-30 Nov 2005; Bahrain, Manama.
- [5] Suraj C. Thombre and M R. Kotwal, Residual Life Assessment, International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181, Vol. 4 Issue 03, March-2015; pp. 1068-1075.
- [6] Isamu Nonaka, Residual Life Evaluation and Repair procedures for high temperature boiling piping, OMMI, Vol. 2 Issue 1, April 2003; pp. 1-14.
- [7] P.M. Padole and M.M. Joshi, Application & Implementation of Residual Life Assessment Techniques for Coal Handling Plant, NDE 2002 predict. assure. improve. National Seminar of ISNT Chennai, 5 to 7 Dec 2002
- [8] Suraj C. Thombre and M R. Kotwal, "Assessment of Residual Life of Engineering Component", Journal of Emerging Technologies and Innovative Research (JETIR), ISSN-2349-5162, Volume 2, Issue 3, March-2015; pp. 723-726.
- [9] A. K. Ray, S. Chaudhuri, N. G. Goswami and R. N. Ghosh, Remaining Life Assessment of Aged Components in Thermal Power Plants and Petrochemical Industries, Vol. 2, ISBN: 81 - 87053 - 73-12008, pp. 85-114.
- [10] R. N. GHOSH, "Remaining Life Assessment of Engineering Components, Recent Trends in Structural Integrity Assessment, National Metallurgical Laboratory, Jamshedpur, 18-19 January 2010; pp. 1-17
- [11] INTERNATIONAL ATOMIC ENERGY AGENCY, "Non-destructive testing for plant life assessment", ISSN 1018-5518, August 2005; pp. 1-60.
- [12] Flavio A. Paoliello, "Guidelines for integrity evaluation and remaining life assessment of recovery boilers- Cenibra's Experience", TAAPI Journal, Vol.4:No.2, February 2005; pp. 17-22.
- [13] V.D. KODGIRE AND S.D. KODGIRE, "Material Science and & Metallurgy for Engineers", Everest Publishing House, 2014; ISBN: 81 863144 00 8