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Creep and life assessment of engineering components in power plants and process industries

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Abstract : *Engineering components in thermal power plants such as boiler tubes, headers, main steam pipes, HP, IP and LP cylinders, rotors etc. made of Cr-Mo, Cr-Mo-V steels and in process industries - steam cracker furnace, reformer tubes, process heater tubes etc. made of HP40, IN 519, HK40 alloys operate in a complex environment involving high temperature, pressure and corrosive atmosphere to perform specific functions for a minimum specified period of time. During service depending upon the operating conditions, several mechanisms such as creep, fatigue, corrosion, oxidation etc. become operative. Accumulation of microstructural damages in the components due to prolong operation decreases their load bearing capacity thereby limiting the lives of the components. When the load bearing capacity falls below a critical level determined by component geometry and loading, failure occurs. This paper describes some aspects of creep and life* *assessment technology and a few case studies related to changes in microstructure due to ageing, creep and remaining life of components in power plants and process industries.*

Key words : Creep life assessment; Power plants; Process industries; Cr-Mo / Cr-Mo-V Steels; HP40 / IN 519 / HK 40 alloys; microstructural changes.

INTRODUCTION

Engineering components in thermal power plants such as boiler tubes, headers, main steam pipes, HP, IP and LP cylinders, rotors and in process industries - steam cracker furnace, reformer tubes, process heater tubes etc. operate in a complex environment involving high temperature, pressure and corrosive atmosphere. During service depending upon the operating conditions, several mechanisms such as creep, fatigue, corrosion, oxidation etc. become operative. Accumulation of microstructural damages in the components due to prolong operation decreases their load bearing capacity. When it falls below a critical level determined by component geometry and loading, failure occurs. Such failure is the major problem concerning the availability of the plants. Since the failure results in non-availability of electric power, loss of industrial production etc., life assessment exercise performed at regular intervals is a means to ensure avoidance of such failures. Some important remaining life assessment methodologies are based on empirical models using creep strain measurement, combined time temperature parameter, tube wall thinning, oxide scale thickness measurement, hardness measurement and microstructural assessment etc. The creep database of indigenously produced, service exposed and failed component materials is used for their metallurgical assessment and remaining life prediction [1-8].

Low alloy ferritic and austenitic steels and alloys are extensively used for large-scale chemical, thermal and petroleum industries primarily due to their high temperature creep resistance[9]. Centrifugally cast austenitic alloys such as HK40, IN519, HP40 etc. have been developed to withstand combination of high metal temperatures, internal pressures and corrosions for an operational life of 100000 hours[10]. Among these various grades of austenitic alloys, reformer tubes made of HK40 alloy are generally designed for an useful life of 100000 hours in a process industry. Numerous research investigations have been carried out, as reported in the literature, to optimize the microstructures and mechanical properties of these alloys[11-15]. Major factors to be considered for selection of such steels and alloys are resistance to creep deformation and rupture, resistance to environmental attack, creep rupture strength and ductility of weld metal and heat affected zone, adequate ductility of base material to avoid sudden failure and also to allow the material to deform rather than fracture in the regions of high stress concentrations. Selection of material for high temperature application, based on temperature dependence of allowable stress, is an important consideration for improving the performance and extending the lives of the plants. The ASME boiler and Pressure Vessel Code, Paragraph A-150 of section I states the criteria for determining allowable stresses. The allowable stresses are not to be higher than the lowest of the following :

- 1/4 of the specified minimum tensile strength at room temperature
- 1/4 of the tensile strength at elevated temperature
- 2/3 of the specified minimum yield strength at room temperature
- 2/3 of the yield strength at elevated temperature

- Stress to produce 1% creep in 100,000 hours
- 2/3 of the average stress or 4/5 of the minimum stress to produce creep rupture in 100,000 hours, whichever is minimum.

These criteria are employed to estimate allowable stresses for a range of steels as a function of temperature. A comparison of the allowable stresses at various temperatures for commonly used steels is shown[16,17] (Fig. 1).

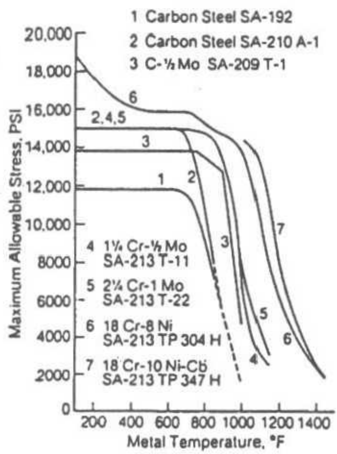


Fig. 1 : Allowable stress for several grades of steels as a function of temperature

For 2.25Cr-1Mo steel, it is the creep rupture strength that determines the allowable stress beyond 482oC. Therefore in the evaluation of creep behavior of Cr-Mo steels, estimation of long-term rupture strength has received considerable importance. Although remaining life assessment of aged components operating in power plant and process industries has attracted world wide attention both from economic and safety view points, a globally competitive and cost effective life assessment technology is yet to be developed.

CREEP LIFE ASSESSMENT METHODOLOGY

Life assessment methodology can broadly be classified into three levels[18]. 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.

One of the crucial parameters in estimation of creep life is the operating temperature. Although steam temperatures are occasionally measured in a boiler, local metal temperatures are rarely measured. Due to load fluctuations and steam-side oxide-scale growth during operation, it is also unlikely that a constant metal temperature is maintained during service. It is therefore more convenient to estimate mean metal temperature in service by examination of such parameters as hardness, microstructure, and thickness of the steam-side oxide scale for tubes. Because the changes in these parameters are functions of time and temperature, their current values may be used to estimate mean metal temperature for a given operating time. The estimated temperature can then be used in conjunction with standard creep rupture data to estimate the remaining life. Several methods for estimation of metal temperature have been reviewed elsewhere[19].

Hardness based approach

Changes in strength of low-alloy steel with service exposure depend on time and temperature. Thus change in hardness during service as shown in Fig. 2 may be used to estimate mean operating temperature for the component.

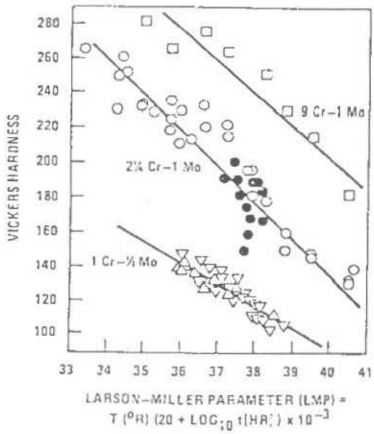


Fig. 2 : Changes in hardness with Larson-Miller Parameter

This approach is particularly suitable when strength changes in service occur primarily as a result of carbide coarsening neglecting stress induced softening. The database on changes in hardness due to long-term service is employed to assess remaining life[19].

Microstructure based approach

Toft and Mardsen demonstrated that there are basically six stages of spheroidization of carbides in ferritic steels. Using Sherby-Dorn Parameter, they established a reasonable correlation of microstructure with mean service temperature[20].

Similar semi quantitative and qualitative approaches involving database on changes in microstructure as a function of service history have been widely used[21].

Oxide scale thickness based approach

Extensive data from literature indicate that in relatively pure steam, the growth of oxide scales is a function of temperature and time of exposure. Several expressions have been proposed in the literature to describe oxide scale growth kinetics [22,23].

REMAINING LIFE ASSESSMENT OF ENGINEERING COMPONENTS

Remaining Life Assessment (RLA) is still a challenging task with its hard core; characterization and quantification of the real damage followed by co-relation of the damage with remaining life. Table 1 and Table 2 present a summary of life-

Table 1 : Life-limiting factors of power plant components operating at elevated temperatures

Plant Area	Critical Components	Typical Materials	Life-Limiting Factors
Boilers	Drums	C-steels	Creep, Thermal fatigue
	Headers	C-steels; Cr-Mo steel; Austenitic steels	CreepThermal fatigue
	Furnace Wall Superheater and Reheater Tubing	C-steelsCr-Mo steels Austenitic steels	Fireside corrosion Waterside corrosion
Pipeworks	Main and Reheat Pipework	Cr-Mo, Cr-Mo-V Austenitic steels	Creep and thermal fatigue; Weld and HAZ cracking
Turbines	HP & IP Rotors	Cr-Mo-V (Nb,W)	Creep, Thermal fatigue
	LP RotorsBlades	Ni-Cr-Mo-V	Fatigue, Corrosion fatigue, Fretting fatigue, PittingStress-corrosion cracking, Temper embrittlement
	Steam Chests Casings	Cr-Mo, Cr-Mo-V	Creep, Thermal fatigue,
	High Temperature bolts	Cr-Mo-V(B) Ni-base alloys	Creep, Thermal fatigue, Stress-corrosion cracking

limiting factors for a variety of components in power plants and process plants respectively[24].

Table 2 : Life-limiting factors of process plant components operating at elevated temperatures

Plant Area	Critical Components	Typical Materials	Life-Limiting Factors
Process Plants			
Steam Reforming Plant	Catalyst Tubes	HK40 (25Cr-20Ni)	Creep, Thermal fatigue, Corrosion, Carburization, Temper embrittlement
	Headers Manifolds	Wrought Alloy 800, ACI IIT 18Cr37Ni	Creep, Thermal fatigue
	Intel Pigtails	C-steels, Low-alloy steels	Creep, Fatigue
	Outlet Pigtails	Alloy 800	Creep, Fatigue

Factors other than the creep are rather very complicated metallurgical phenomena and are taken care in design indirectly by the safety factor. It is being increasingly realized that the design is conservative mainly on account of a high safety factor of 1.6 and conservative creep database (scatter of ± 20% on mean stress) used for the purpose. Consequently, the life can be extended several folds of the design life. In oil refineries and fertilizer industries, a number of process plants are used at high temperature and pressure. These are often operated for periods substantially in excess of coded design life. Here in most cases, the operating temperatures and pressure are rather moderate. For example, components like process heater tubes, CCU reactor and FPU columns as used in oil refineries experience operating temperature of 450°-600°C, and pressure (in terms of hoop stress) around 20 MPa. Under such condition it is not unusual for them to operate safely for 40-50 years if RLA is systematically carried out with due regard to other life limiting factors like corrosion and thermal fatigue. In sharp contrast to the above, some components operate under very severe condition e.g. reformer tubes (centrifugally cast austenitic alloy tubes) as used in reformer furnaces operate at 850°-1000°C and at internal pressure of 25-35 kg/cm^2.

Creep life assessment of platen superheater and reheater tubes

Service exposed Platen superheater (PLSH) and Reheater (RH) tubes of a thermal power plant were identified for remaining creep life assessment study[25]. The grade of steel, dimensions and identification nos of these tube samples are given in Table 3.

Table 3 : Material Specification for Boiler Tubes

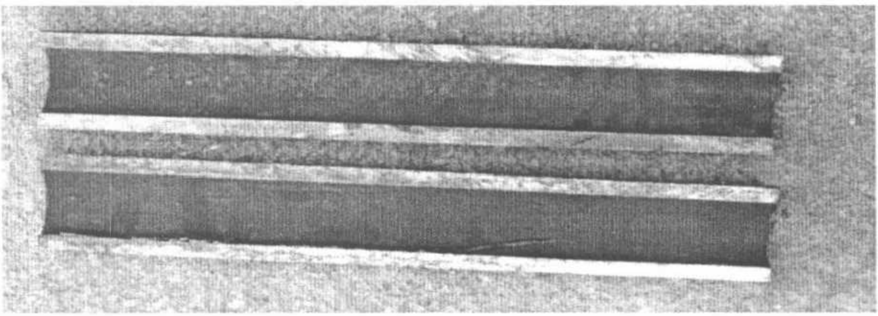
Tube Sample	Identification	Nominal Dimension ODXTh, mm	Measured Dimension ODXTh, mm	Grade of Steel
PLSH Coil (Outlet)	L - R - CKT - 25	51 X 8.8	51.48 X 8.91	SA 213 T22
RH Coil (Outlet)	L - R - CKT - 1	54 X 3.6	54.28 X 5.03	SA 213 T22

The operating parameters of the service-exposed tubes as obtained from the plant engineers are given in Table 4.

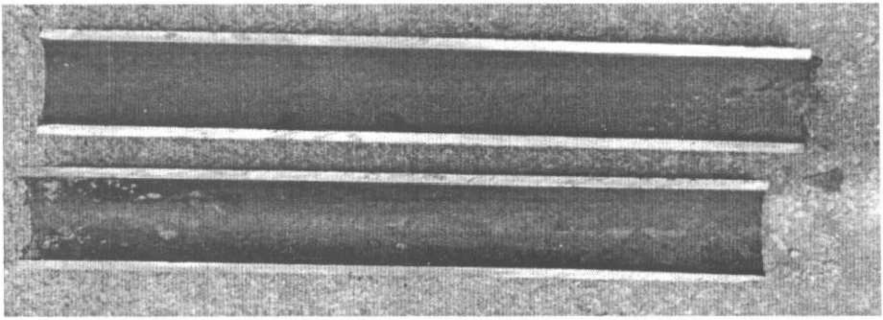
Table 4 : Operating Parameters of Service Exposed Tubes

Tube Sample	Designed Steam temperature °C	Operating pressure Kg/ cm^2	Length of serviceHours	Zone
PLSH tube (Outlet)	544 °C	158.2	59,585	PlatenSuperheater
RH tube (Outlet)	580 °C	33.5	59,585	Reheater

The experimental work undertaken for assessing remaining life of service exposed boiler tubes includes tensile tests, hardness measurement, microstructural examination and creep rupture tests. The test data so generated have been analyzed and compared with NRIM data for 2.25Cr-1Mo steel to examine the influence of service exposure on mechanical properties and remaining life of boiler tubes.



(a)



(b)

Fig. 3(a,b) : Service exposed Platen Superheater and Reheater Tube Samples

Figs. 3(a,b) show the longitudinal section of service exposed platen superheater and reheater tube samples received from the plant for RLA study. Both the tubes showed grayish oxide layer on the inner surfaces. The measured outer diameter and thickness of the service-exposed tubes are given in Table 5.

Table 5 : Measured Dimensions of Service Exposed Tubes

Tube Nos.	Outer diameter, mm	Thickness, mm
L - R - CKT - 25	51.48	8.91
L - R - CKT - 1	54.28	5.03

Tensile tests and hardness measurement

Standard tensile specimens were made from the longitudinal direction of the service exposed boiler tubes to carry out tensile tests in air using Instron 8562 servo electric machine at a constant displacement rate of 0.008 mm/sec. The range of temperature selected for tensile tests are from 25°C to 650°C for both the platen superheater and reheater tubes. Hardness measurement at 25°C was carried out on specimens selected from each type of boiler tube. The results of tensile tests viz. YS/0.2% PS, UTS and %Elongation as a function of temperature as well as hardness measurement for PLSH and RH tubes are shown in Table 6 (a,b).

Table 6(a) : Tensile Properties & Hardness Measurement of Service Exposed PLSH Tubes

Tube No	Temperature °C	YS / 0.2%PS, MPa	UTS, MPa	% Elongation	Hardness HV30
L-R-CKT-25	25	248	453	19	137
L-R-CKT-25	600	143	180	33	
L-R-CKT-25	650	117	139	37	

Table 6(b) : Tensile Properties & Hardness Measurement of Service Exposed RH Tubes

Tube No	Temperature °C	YS / 0.2%PS, MPa	UTS, MPa	% Elongation	Hardness HV30
L-R-CKT-1	25	259	501	14	143
L-R-CKT-1	600	166	227	19	
L-R-CKT-1	650	129	167	21	

The temperature dependence of 0.2% PS / YS data and UTS data of both the tubes are shown graphically in Figs. 4 and 5 respectively. For the purpose of comparison, the minimum NRIM data are also shown in these figures.

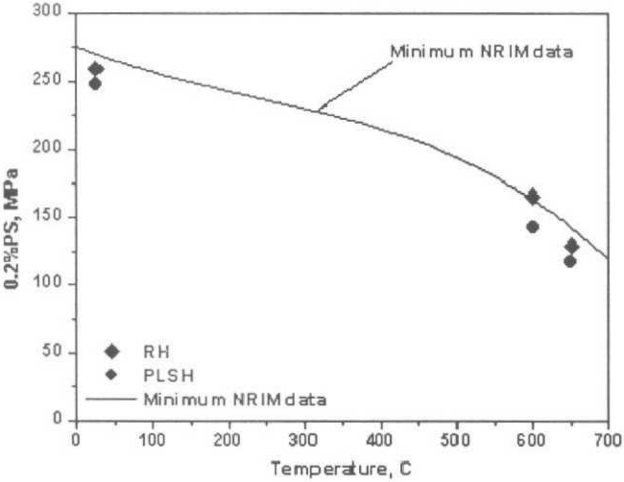


Fig. 4 : Temperature Dependence of 0.2% PS of PLSH & RH Tubes

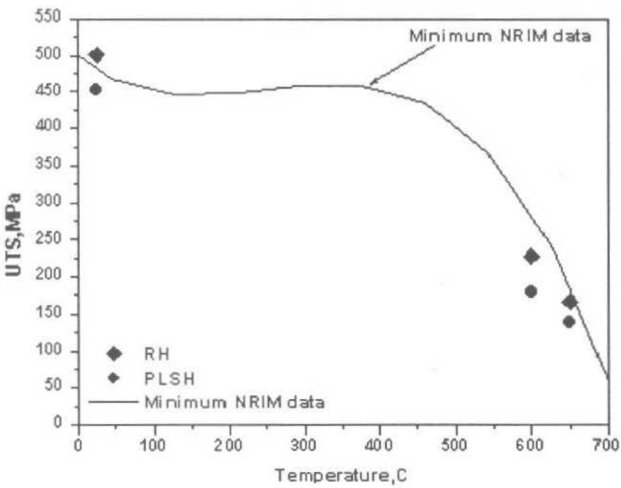


Fig. 5 : Temperature Dependence of UTS of PLSH & RH Tubes

Microstructural examination

Specimens for microstructural examination using optical microscope were made following standard procedure from the transverse direction of the service-exposed tubes. Microstructures obtained at different locations of service exposed platen superheater and reheater tubes are shown in Figs. 6(a,b) and Figs. 7(a,b) respectively.

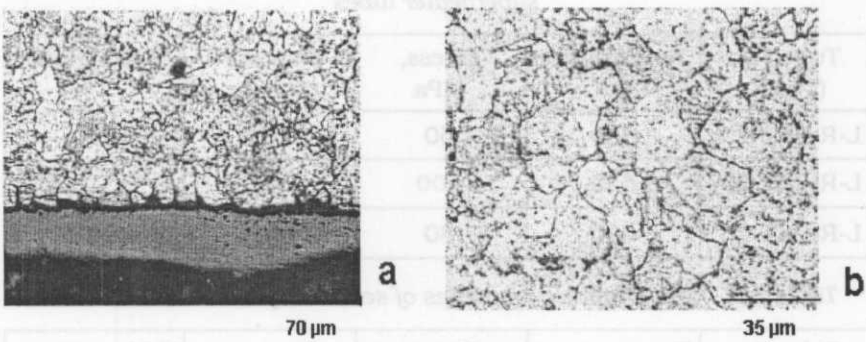


Fig. 6 : Microstructures at (a) Inner Section and (b) Midsection of Service Exposed Platen Superheater Tube

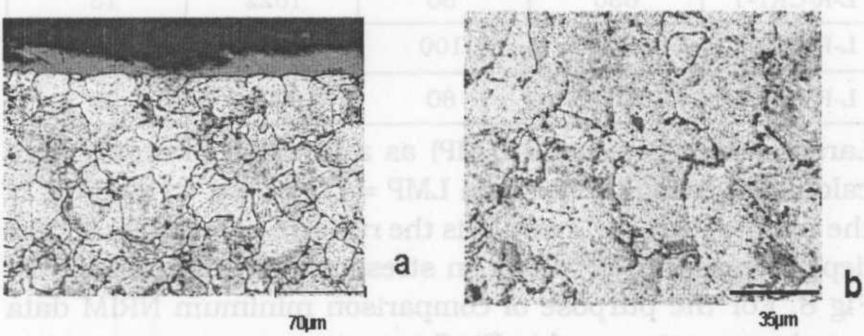


Fig. 7 : Microstructures at (a) Inner Section and (b) Midsection of Service Exposed Reheater Tube

Creep rupture tests

Standard test specimens were made from the longitudinal direction of the service exposed boiler tubes to carry out creep rupture tests in air using Mayes creep testing machines. The temperature levels selected for these tests are 600°C and 650°C. The stress levels for these tests are selected to obtain rupture within a reasonable span of time. The results of creep rupture tests of the specimens made from PLSH and RH tubes are shown in Table 7(a,b):

Table 7(a) : Creep rupture properties of service exposed platen superheater tubes

Tube No (Type)	Temperature °C	Stress, MPa	Rupture time, hr	% Elongation
L-R-CKT-25	650	50	1073	29
L-R-CKT-25	600	100	144	31
L-R-CKT-25	600	80	851	28

Table 7(b) : Creep rupture properties of service exposed reheater tubes

Tube No (Type)	Temperature °C	Stress, MPa	Rupture time, hr	% Elongation
L-R-CKT-1	650	50	1022	13
L-R-CKT-1	600	100	1057	21
L-R-CKT-1	600	80	2904	28

Larson-Miller-Parameter (LMP) as a function of stress were calculated using the formula LMP = T(20 + log tr) where T is the temperature in °K and tr is the rupture time in hours. The dependence of LMP values on stress is shown graphically in Fig 8. For the purpose of comparison minimum NRIM data are also superimposed in Fig 8.

Visual examination did not reveal presence of any significant oxidation / corrosion damages on the outer surfaces of both tubes. The inner surfaces, however, showed the presence of grayish oxide layer (Fig. 3a,b). The reduction in tube wall thickness in reheater and platen superheater tubes as

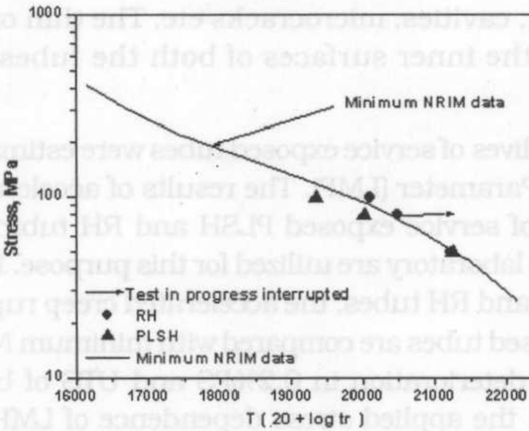


Fig 8 : Stress vs. LMP Plot of Platensuperheater and Reheater tubes

obtained from measurement and compared with the specified thickness was not observed.

The results of tensile tests of service exposed PLSH and RH tubes reveal the following features based on comparison with NRIM data for the same grade 2.25Cr-1Mo steel tube[26]:

In general, deterioration in 0.2%PS (Fig.4) and UTS (Fig.5) of both PLSH and RH tubes, when compared with minimum NRIM data, was observed. The RH tubes exhibit higher 0.2%PS and UTS than that of PLSH tubes irrespective of test temperature. The extent of degradation is more pronounced in case of PLSH tube. The 0.2%PS at 600°C and UTS at 25°C of RH tube meet the minimum NRIM data.

The microstructures, in general, consist of degenerated bainitic regions in terms of spheroidisation of carbides. Such microstructural features are expected from the tubes, which have undergone a prolonged service exposure. The extent of degeneration of bainitic regions is almost similar in PLSH and RH tubes (Figs. 6b & 7b). The microstructural features did not reveal presence of any significant damages such as graphitisation, cavities, microcracks etc. The thin oxide scale is present at the inner surfaces of both the tubes (Figs. 6a & 7a).

The remaining lives of service exposed tubes were estimated using Larson Miller Parameter (LMP). The results of accelerated creep rupture tests of service exposed PLSH and RH tubing steel as obtained in the laboratory are utilized for this purpose. In absence of virgin PLSH and RH tubes, the accelerated creep rupture data of service-exposed tubes are compared with minimum NRIM data. In contrast to deterioration in 0.2%PS and UTS of both PLSH and RH tubes, the applied stress dependence of LMP for these tubes as shown in Fig. 8 clearly indicate that the creep properties of both tubes at 50 MPa meet the minimum properties when compared with NRIM data. At a stress level of more than 50 MPa, the creep rupture data of PLSH tube fall marginally below the creep rupture data of RH tube. The deviation in terms of LMP is longer at higher applied stress of more than 50 MPa and gradually increases with increasing applied stress. Although the operating hoops stress as estimated from the nominal tube dimension and operating pressure is 37 MPa for PLSH tube and 16 MPa for RH tube, the remaining life has been estimated from experimentally obtained creep rupture data at the lowest stress level of 50 MPa and reported in Table 8.

Table 8 : Remaining life of PLSH and RH tube

Tube Nos	Type of tube	Estimated Life, Years
L-R-CKT-25	Platen superheater tube	>>10 years at 570°C; 50 MPa
L-R-CKT-1	Reheater tube	9 years at 580°C; 50 MPa

Based on accelerated creep rupture tests and analysis of data, it can be said that the service exposed platen superheater and reheater tubes are in a good state of health for its continued service provided no localized damages in the form of tube wall thinning, circumferential expansion, excessive oxide scale formation, microstructural degradation etc are present besides adherence to the specified operating parameters in service. The PLSH tube may be allowed to remain in service for a period of 10 years under similar operating condition provided tube wall temperature does not exceed 570°C. The RH tube may be allowed to remain in service for a period of 9 years under similar operating condition provided tube wall temperature does not exceed 580°C.

A more reliable estimate of remaining life is obtained by considering simultaneously NDT measurement at site and their analysis, actual operating history, destructive tests and their analysis in the laboratory.

Creep life assessment of reformer tubes

For creep life assessment of service exposed reformer tubes, three reformer tube samples marked as 121, 144A and 144B from a fertilizer plant were identified[27]. These are shown in Fig.9. The material specification and operating history of the plant are described below:

Fig. 9 : As received reformer tube samples

Primary reformer for ammonia plant of Haldor Tposoe design is the furnace containing 288 catalyst tubes arranged in two radiant chambers of 144 tubes each. The catalyst tubes are vertically installed and supported at the bottom and are free to expand in upward direction. The feed gas, of naptha vapours and steam, enters from the top end at a temperature of 490°C and a pressure of 32 kg/cm^2 and flows down through the catalyst contained in individual tubes before coming out at a temperature of 780°C and a pressure of 31 kg/cm^2. The reaction taking place in the reformer tubes is endothermic. For this, heat is provided by firing of 576 burners located at various elevations in the furnace.

The heat is transferred to the tubes through radiation and the metal temperature is maintained between 870°C and 890°C. The chemical composition of the material and the operating conditions of the tubes are given in Table 9.

Table 9 : Chemical composition and operating conditions of primary reformer tube

Tube material	HP40 + Nb microalloy
Composition (wt%)	C: 0.45, Si: 1.5, Mn: 1, Cr:25, Ni: 35, Fe: Balance
Tube size	OD:152 mm; Thickness:10.7 mm
Design Temp.	906°C
Design Pressure	34 kg/cm^2 (3.33 N/mm^2)

At the time of failure the reformer was being started up with only 60 burners firing in the reformer. The gas in the reformer was mainly hydrogen and steam at a pressure of 3 kg/cm^2 only. Seven tubes ruptured in the bottom portion in one corner of the radiant chamber. Other two tubes ruptured away from this zone in the bottom portion. The rupture is longitudinal. These tubes have been in operation for two years. Dimensional measurement on the tubes carried by the plant is given in Table 10.

Table 10 : Dimensional measurement of the tubes carried out at the plant

Tube no	Crack length, mm	Max. OD mm	Crack opening, mm	L, mm	Pig tail dia, mm
144	850	160	19		
143	570	160.7	12.4		
142	880	159	16		
141	630	158	17		
140	620	158.6	13		
139	630	157.4	10		
138	500	156.9	11.5		

The fertilizer plant had supplied the following information :

- The failed tubes were replaced with new tubes and as per the practice, the pressure drop in each tube was measured. The pressure drop in case of Tube no. 121 was found to be more. The pig tail corresponding to this was cut open and chocking due to damage catalyst was observed as reported by plant engineers.
- Chances of steam / water entrapment in the tube were explored. It was found that the possibility of water entrapment is very less because during shutdown, nitrogen is passed through all tubes at a pressure of 6 kg/cm^2 for 24 hours
- Temperature in the radian zone where 7 Nos. of tubes numbering 138-144 had failed was reported to be very high. This was observed when plant engineers looked through manhole soon after the tube failures.

- Possibility of burning hydrogen coming out from the leaked tube cannot be ruled out.
- Details regarding how many burners (out of 60) were firing in the bottom zone where failure had occurred were not available.

Visual examination

Both inner and outer surfaces of the service exposed reformer tubes were examined. The tube showed the presence of rather black adherent oxide scale at the outer surface, which is an indicative of prevalence of high temperature. Sign of any localized damage in the form of pits were not observed. The expansion in the outer diameter of the tube was not significant as can be seen from the data given in Table 11.

Table 11 : Change in the outer diameter of the tubes

	Tube No.144A	Tube No.144B	Tube No.121
Max. transverse opening, mm	–	20	10
Tube thickness, mm	12	12	12
Circumference excluding max. transverse opening, mm	-	495	490
Circumference away from rupture zone, mm^2	490	490	490

Microstructural examination

Optical metallographic specimens were prepared from the service exposed reformer tubes viz. 144A, 144B and 121. The typical microstructure of tube 144A is given in Fig.2. The microstructures, observed at various circumferential locations in tube 144B, are given in Fig.3. Hardness values are also reported against each microstructure. The typical microstructures and hardness values observed in the case of sample No.121 are reported elsewhere[28].

Microstructures near the inner and outer surfaces of the failed tube No.144B were also examined. Evidence of carburization/ decarburization were not observed.

From the above photomicrographs the following observations can be made.

- In the top portion (144A) of the reformer tube, the microstructure consists of austenitic matrix with inter-dendritic eutectic carbides (Fig.10).

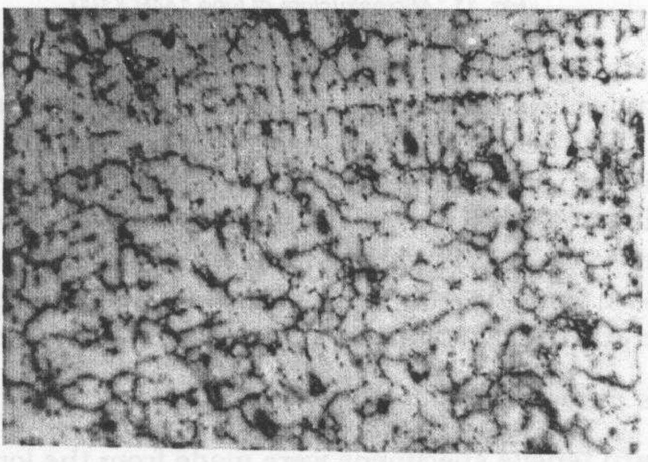


Fig. 10 : Microstructure of tube 144A,X100

- In case of tube No.144B tube, the inter-dendritic eutectic carbides have coarsened. The presence of coarse carbide inside austenitic grains may also be noted (Fig.11). Comparison of the microstructures of Tube Nos.144B & 121 indicates that the tube No.121 has seen a lower temperature[28]. This is mainly based of the fact that the carbides inside the austenitic grain have not coarsened as remarkably as in tube No.144B.

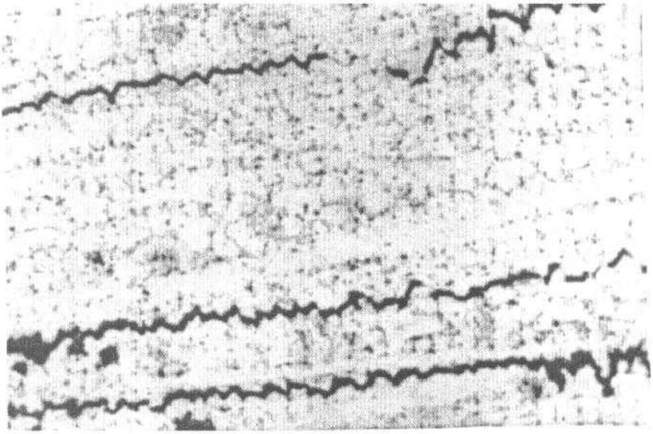


Fig. 11 : Microstructure of tube 144B,X100

For the purpose of determination mechanical properties and remaining life of service exposed reformer tubes, worst affected tube (No.144B) is selected based on the results of visual examination and microstructural study. In order to study the influence service exposure on mechanical properties and remaining life of this worst affected tube, an unfailed sample (No.144A) from the same reformer tube is additionally selected for the purpose of comparison in absence of any virgin tube.

Tensile properties

Standard tensile specimens were made from the longitudinal direction of the service exposed reformer tubes 144A and 144B to carry out tensile tests in air using Instron 8562 servo electric machine at a constant displacement rate of 0.003 mm/sec. The temperature range selected for tensile tests was 25°C and 800°C to 950°C at an interval of 50°C. Hardness measurement at 25°C was carried out on specimens selected from each reformer tube.

The result of tensile tests viz. 0.2% PS, UTS, % elongation (EL) and % reduction in area (RA) as functions of temperature are given in Table 12.

Table 12 : Tensile properties of reformer tube

Sl.No.	Temp.oC	0.2% PS, MPa	UTS, MPa	%EL	%RA
	144A (Top portion)				
1	Room Temp.	390	577	06	09
2	800	172	193	34	51
3	850	134	157	43	52
4	900	115	130	37	58
5	950	92	102	30	54
	144B(Bottom portion)				
1	Room Temp.	256	439	09	12
2	800	133	155	41	48
3	850	96	116	28	59
4	900	74	90	48	64
5	950	66	71	39	61

The temperature dependence of 0.2% PS and UTS data are shown graphically in Figs.12-13. For the purpose of comparison, typical manufacturer's values are also shown in these figures. Deterioration in the tensile properties in terms of 0.2% PS and UTS values of the reformer tube (144B) may be noted. This observation is in accordance with the hardness data. The hardness in case of 144B is about 160VHN as against 221 VHN for the reformer tube 144A[28]. The deterioration in the tensile properties in terms of 0.2% PS and UTS values of the reformer tube (144B) is also observed when compared with minimum NRIM data[29]. The tensile ductility data in terms of % EL and % RA of the reformer tubes (144A and 144B) are found to be superior when compared with minimum NRIM data.

Creep rupture properties

Standard test specimens were made from the longitudinal direction of the service exposed reformer tubes 144A and 144B to carry out creep rupture tests in air using Mayes creep testing machines. The temperature levels selected for these tests are in the range of 900°C to 960°C at an interval of 20°C. The stress levels at each temperature were selected from typical manufacturer's data to obtain rupture within 1000 hours.

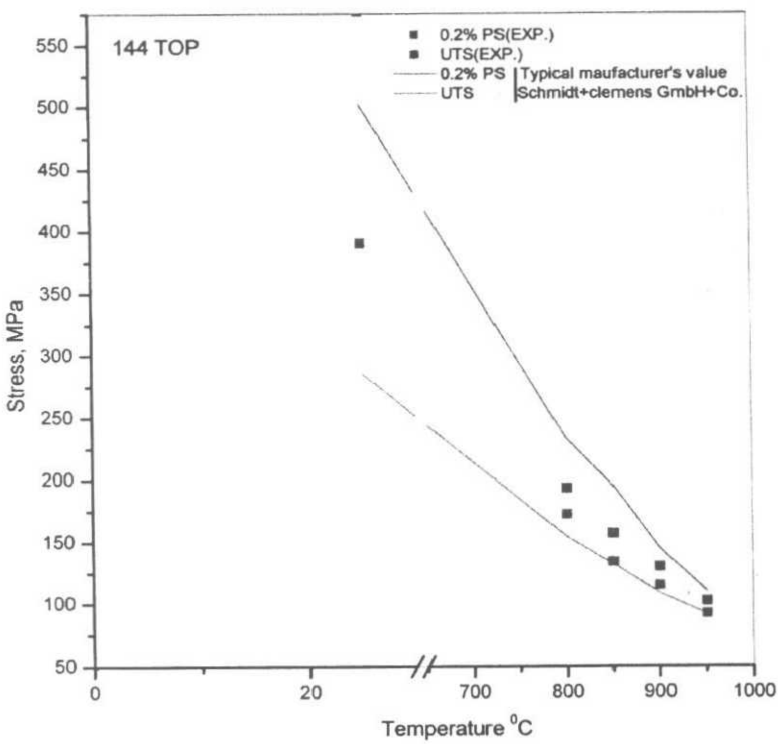


Fig. 12 : Dependence of 0.2% PS and UTS on temperature of tube 144A

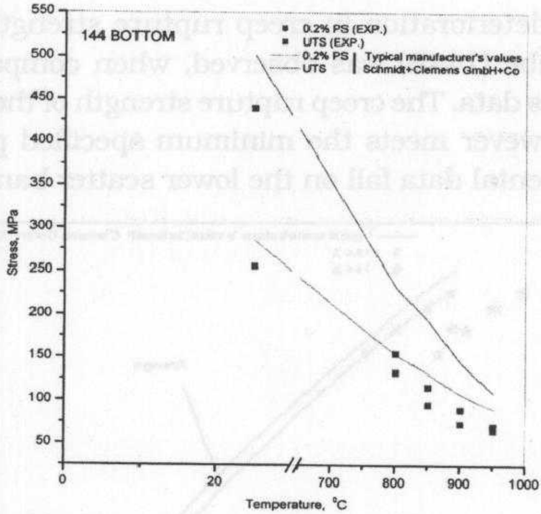


Fig. 13 : Dependence of 0.2% PS and UTS on temperature of tube 144B

The results of creep rupture tests are given in Table 13. Larson Miller Parameter (LMP) as a function of stress was calculated using the formula LMP = T(22.9 + log tr) where T is the temperature in K and tr is the rupture time in hours. The dependence of LMP values on stress is shown in Fig. 14.

Table 13 : Tensile properties of reformer tube

Tube No	Temp°C	Stress MPa	Rupture time, hrs	%EL	%RA
144A	900	46.25	1104	2	7
144A	920	42.32	895	4	5
144A	940	37.36	1034	3	2
144A	960	32.55	1211	3	8
144B	900	46.25	71	21	51
144B	900	42.32	223	31	58
144B	920	42.32	69	34	65
144B	920	37.36	358	36	55
144B	940	37.36	83	28	64
144B	940	32.55	85	29	63

A significant deterioration in creep rupture strength in case of reformer tube (144B) was observed, when compared with manufacturer's data. The creep rupture strength of the reformer tube 144A however meets the minimum specified properties as all experimental data fall on the lower scatter band.

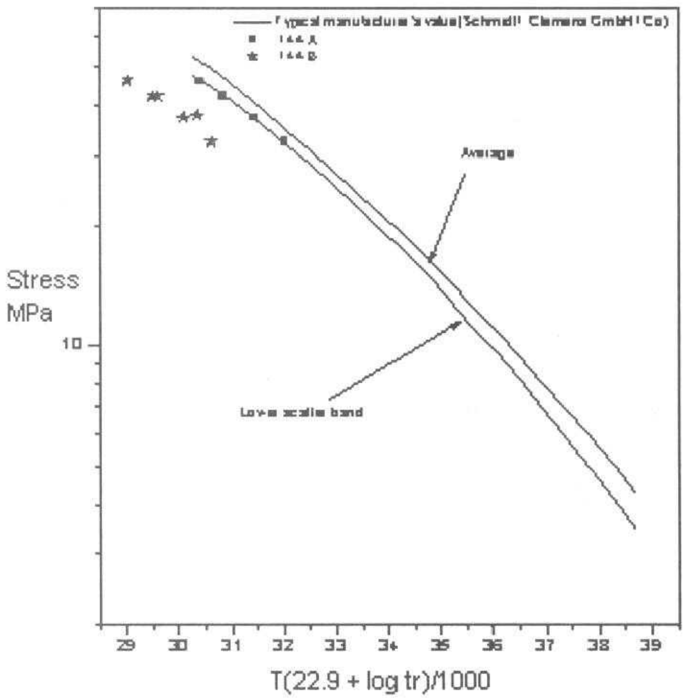


Fig. 14 : Stress versus LMP plot of reformer tubes 144A and 144B

DISCUSSION AND CONCLUSION

The factors, which can influence the serviceability of reformer tubes, are

- Deficiency in reformer tube material in terms of mechanical properties, inherent defects etc.
- Heavy surface damages like decarburisation and carbonization

- Localized damages in the form of sharp cracks or pits
- Overheating with or without increase in pressure

The mechanical properties viz. tensile and creep rupture strength in the top portion (144A) of the reformer tube have been found to be in good agreement with the specification and no surface and localized damages have been observed. In contrast the following evidences supporting overheating in the bottom portion (144B) of the reformer tube have been found :

- Coarsening of carbides inside austenite grain as well as that of inter-dendritic carbides (Fig. 11)
- Significant drop in tensile strength, hardness and creep rupture strength in the bottom portion (144B) of the reformer tube (Fig. 13 and Fig. 14)
- Plant engineers also observed excessive redness in the radiation zone.

Overheating thus appears to be the dominant factor limiting the serviceability of the reformer tubes. The various events responsible for such overheating had been discussed in the report on failure analysis of reformer tubes[29].

From stress vs. LMP plot (Fig. 14), the remaining lives of the top 144A and the bottom 144B prtion of the reformer tubes have been estimated at the design temperature and pressure. The estimated remaining life at 900oC and 22.5 MPa as obtained from Fig. 14 are given below :

Tube no. 144B	Tube no. 144A
About 2 years	More than 10 years

In conclusion, it may therefore be said that overheating during service is primarily responsible for significant degradation in mechanical properties and microstructures in the bottom portion (144B) of the reformer tube. Overheating thus appears to be the dominant factor limiting the life of the reformer tubes. The reformer tubes, which had experienced similar overheating in service, are recommend for replacement. Alternatively the overheated tubes may be reinstalled by turning them through 180° so that the bottom portion of the tubes occupies the location at the top, which is relatively at a lower operating temperature.

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