Mechanical Property Evaluation and Remaining Life Assessment of Service - Exposed Steam Pipe of Boilers in a Thermal Power Plant

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ABSTRACT

This paper is aimed at investigating the residual life of more than eleven years service - exposed main steam pipes of various boilers in a thermal power plant. The remaining life assessment for safety were made using destructive accelerated stress rupture and tensile tests at different temperatures, and some nondestructive tests. There was no evidence of localised damage in the form of surface cracks, cavitation or dents in the service exposed main steam pipes of all the boilers. So far as the remaining life at 823 K is concerned, it is possible to obtain a life of greater than 100000 hours, both at the allowable as well as operating hoop stress levels of the service - exposed pipes, provided no localised damage in the form of cracks or dents has been developed. It is recommended that a health check should be carried out after 50,000 hours of service exposure at 823 K.

Key words: Service exposed, steam pipe, boilers, stress rupture test, tensile properties, residual life.

1. INTRODUCTION

It is widely known that carbon and Cr-Mo steels are extensively used as high temperature components in power plants /1-7/. Even though most of these components have a specific design life of 20 years, many of these have been known to have survived much longer. In view of the increasing cost of setting up a new plant, there is now considerable interest in life extension of the existing units. In order to arrive at a quantitative estimate of the remaining life of such ageing components, it is necessary to have some creep and stress rupture data.

The latest studies on the design methodology and life estimation for major components for steam turbines were reviewed /6/. Relationships for calculating the actual creep damage have been clarified by many studies. Several revolutionary devices have been introduced, so that one can detect local creep and fatigue damage. Studies of life estimation of welded joints in the design stages show that the remaining life of such components can be analysed from creep and stress rupture properties by defining a reference stress such that the component life equals to the life of a simple specimen tested at the reference stress. Keeping this in view, over the years attempts are being made to generate such data on similar components /4-7/.

The aim of the present work is therefore to evaluate the remaining life of more than eleven years service exposed main steam pipe of boilers, based on experimentally determined tensile and stress rupture properties of service exposed materials.

2. MATERIAL AND HISTORY OF THE SERVICE-EXPOSED MAIN STEAM PIPES OF THE BOILERS:

The material specifications with service conditions and history of operation of the service exposed main steam pipe of all the boilers under the same operating conditions but with different service exposures are given in Table 1.

Table 1a

Material specification and service condition of the service- exposed main steam pipes

Material:	1 Cr-0.5 Mo-0.25 V - Russian Graded Steel (12 X 1M4)
Design Stress:	45.8 Mpa
Operating Temperature:	823 K
Allowable Stress:	65 Mpa
Service Condition:	
Steam Pressure in the main steam pipes:	90 ± 5 atm
Steam Temperature:	808 ± 13 K
Boiler Capacity:	240 tonnes of steam/hour

Table 1b

History of operation

Sl. No	Type of Main Steam Pipe	Service exposure (hrs)
1	Boiler D	166000
2	Boiler E	167000
3	Boiler F	106000
4	Boiler G	105000
5	Boiler H	100000
6	Boiler I	11 2000

2.1 Dimension and visual examination of the pipe:

The outer diameter and length of the pipes were 273 mm and 450 mm respectively. The average wall thickness of the main steam pipes varied between 20-23 mm. There was also no evidence of localised and general corrosion/oxidation on either external or internal surfaces of the pipes. Dimensions of the outer diameter (OD) were measured at two mutually perpendicular directions along the length of the pipe at an interval of 150 mm.

3. EXPERIMENTAL

Chemical analysis as revealed in Table 2 shows that the materials in the present investigation are basically Cr-Mo steels conforming to the Russian Grade specified.

Optical metallographic examinations (Figs. 1 and 2) were carried out on the virgin, service-exposed main steam pipe of all boilers (D,E,F,G, H& I). The hardness values in the base for boilers are shown in Table 3.

Tensile tests at room temperature, 623 K, 673 K, 723 K, 773 K, 832 K, 873 K and 923 K of the service - exposed base metal were performed using a digitally controlled 8562 Instron servo-electric testing system, equipped with a 3-zone split furnace with PID control. Standard tensile specimens were made from the service-exposed materials as per ASTM E8-79 specification. Tensile tests were carried out on the base metal only from the longitudinal direction of the main steam pipes

Table 2

Chemical analysis and virgin and service-exposed main steam pipes of boilers

Sl. No	Type of Main Steam Pipe	Mass % of Elements Present											
		C	Mn	Si	S	P	N	Cr	Mo	V	Ni	Cu	Sb
1	Virgin	0.08	0.40	0.17	0.025	0.025	-	0.90	0.35	0.20	0.25	0.20	-
2	Boiler D	0.10	0.50	0.25	0.011	0.007	-	1.11	0.25	0.23	-	-	-
3	Boiler E	0.12	0.56	0.28	0.011	0.007	-	1.11	0.22	0.22	-	-	-
4	Boiler F	0.10	0.54	0.24	0.012	0.008	-	1.12	0.27	0.23	-	-	-
5	Boiler G	0.06	0.56	0/25	0.011	0.007	-	1.13	0.27	0.24	-	-	-
6	Boiler H	0.08	0.61	0.26	0.033	0.013	-	1.25	0.22	0.29	-	--	-
7	Boiler I	0.08	0.61	0.26	0.033	0.013	-	1.25	0.22	0.29	-	-	-

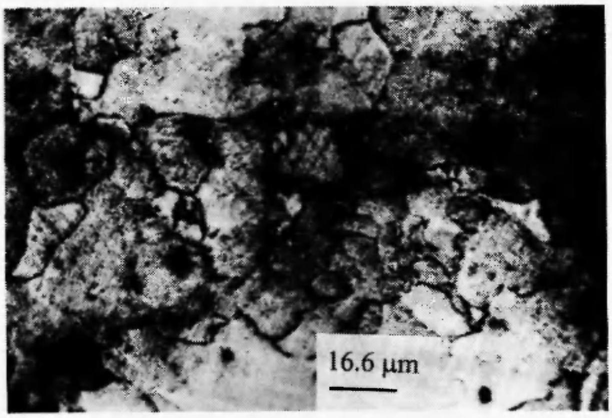

Fig. 1: Optical micrograph of the virgin pipe at X 600, revealing ferrite grains dispersed with carbides. There is no evidence of graphitization and creep damage in the form of cavities and decarburization

Fig. 2: A typical optical micrograph of service exposed main steam pipe of boilers at X 300, revealing ferrite grains dispersed with carbides. There is no evidence of graphitization and creep damage in the form of cavities and decarburization. This photomicrograph is for boiler D.

of the service exposed boilers. During tensile test, constant test temperature within ±2 K and a constant displacement rate of ± 0.2 mm/min were maintained. The variation of the Yield Strength (0.2% Proof Stress) and Ultimate Tensile Strength (UTS) with temperature of testing is shown in Figs. 3a and 3b. Figs. 3c and 3d

Table 3
Hardness values of the virgin and service exposed main steam pipes

Sl.No	Type of main steam pipe	Hardness Value (VHN)
1	Virgin	153
2	Boiler D	143
3	Boiler E	149
4	Boiler F	145
5	Boiler G	150
6	Boiler H	151
7	Boiler I	142

show the variation of % RA (reduction in area) and % EL (elongation) with temperature of testing respectively.

The hoop stress σ_h acting on the service - exposed pipes can be calculated using the following formula to predict the remaining life:

$$\sigma_h = PD/2t \tag{1}$$

where P is the operating pressure in MPa, D is the mean diameter in mm and t is the thickness of the pipe in mm. The operating hoop stresses for the different main steam pipe of boilers D, E and F as evaluated from the above formula were 52.1 MPa, 50 MPa and 58 MPa respectively. Incidentally, the operating hoop stresses for boilers H & I were the same as that for boiler E. Also the operating hoop stress for the main steam pipe of boiler G was the same as that of boiler F.

Although the design stress and operating temperature were 45.8 MPa and 823 K respectively it was decided that the accelerated stress rupture tests to be carried out in the range of 798 K to 963 K and the lives were evaluated at 65 MPa, since the allowable stress level of the boilers is 65 MPa. Accelerated stress rupture tests using Mayes creep testing machines were carried out as per ASTM 139/83 specification with specimens made from the chordal direction of the main steam pipe of each boilers. These tests were carried out at various stress level in the range of 65-200 MPa for the virgin pipe and 65-190 MPa for the sevice exposed

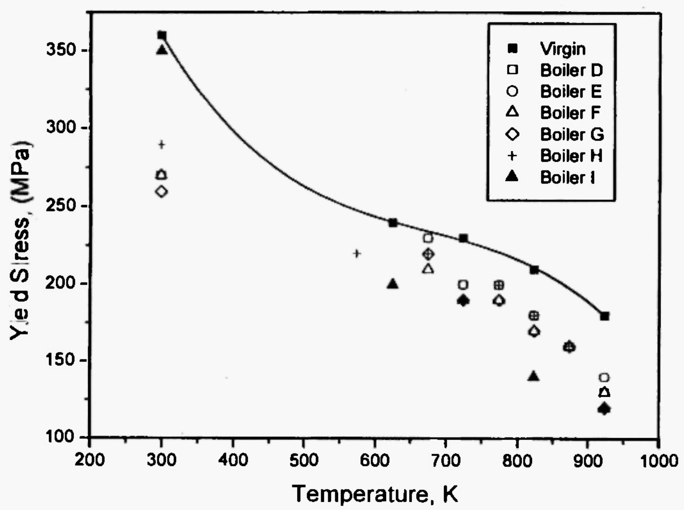

Fig. 3a: Plot of yield strength (0.2% proof stress) Vs test temperature for virgin and service exposed boiler pipes.

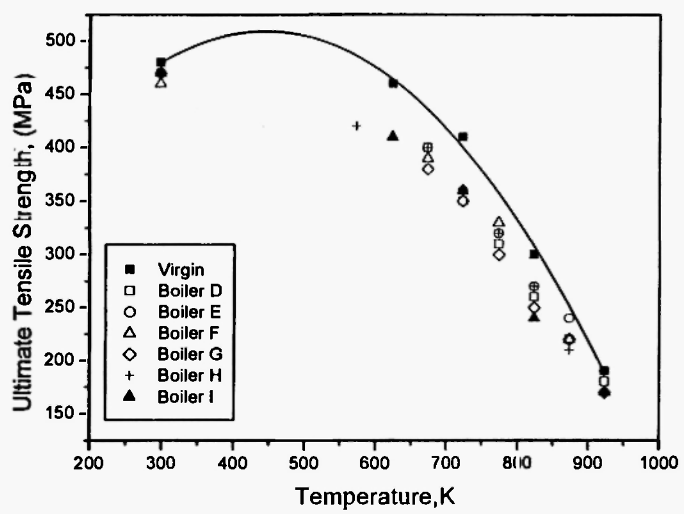

Fig. 3b: Plot of ultimate tensile strength (UTS) Vs test temperature for virgin and service -exposed boiler pipes.

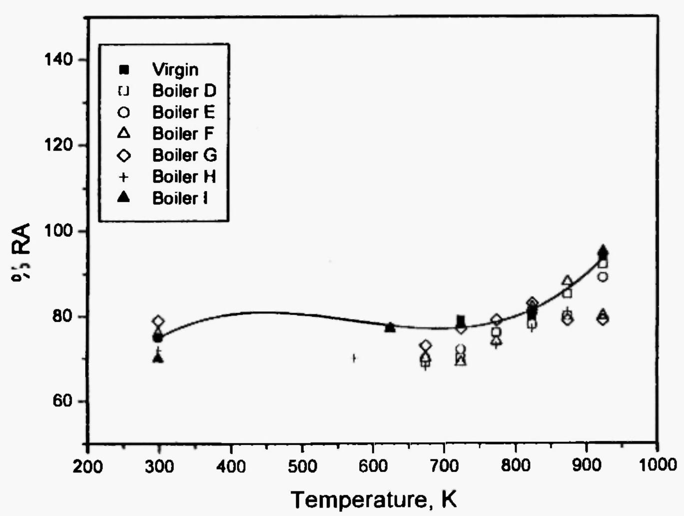

Fig. 3c: Plot showing variation of % reduction in area (%RA) with test temperature for virgin and service- exposed boiler pipes.

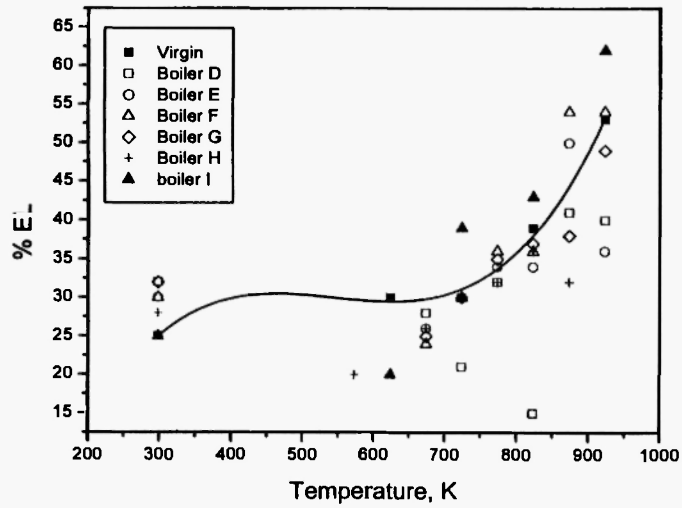

Fig. 3d: Plot showing variation of % elongation (%EL) with test temperature for virgin and service -exposed boiler pipes.

steam pipes,to generate data with high extrapolation capability. The stress levels above the operating hoop stress at each temperature were selected in such a way as to obtain rupture within a reasonable span of time.

The generation of stress rupture data was carried out in two ways:

(a) *Increased temperature tests*: At a constant stress of 65 MPa, acceleration was achieved by increasing the test temperature above the specified service temperature which is about 823 K. The range of temperature selected for the tests for various service exposed main steam pipes varied from 798 K to 963 K. To generate more meaningful stress rupture data for life prediction methodology, stress levels even beyond 65 MPa (allowable stress) to a maximum of 190 MPa were selected.

(b) *Increased stress test*: Acceleration was achieved by increasing the stress level beyond 65 MPa which is the allowable stress level specified. Keeping the temperature constant at 823 K, the stress levels selected for these tests were in the range 110-190 MPa.

The stress rupture data under the above stipulated conditions of acceleration are given in Table 4.

The rupture data for the specimens have been plotted in terms of log (stress) vs Larson-Miller Parameter {LMP = $T(20 + \log tr)$}, where T is the Absolute temperature in K and tr is the rupture time in hours. For the purpose of comparison, the best fit curve using third order polynomial for the virgin pipe has been superimposed on this plot. Regression analysis of stress rupture data for virgin as well as service exposed main steam pipes has been carried out using a standard software package, in order to evaluate the long term rupture strength of the components over a range of temperatures presently investigated.

$$\text{Larson- Miller Parameter } (LMP) = T\,(C + \log tr) = a_o + a_1(\log S) + a_2\,(\log S)^2 + \ldots\ldots + a_m\,(\log S)^m \quad (2)$$

where T = Temperature in K
tr = Rupture time in hrs
S = Rupture strength rupture in MPa
m = Order of polynomial
C~ 20 for these materials

m, a_o, a_1 a_2 & a_3 are polynomial constants. Table 5 shows the rupture strengths (S) of the service exposed pipes for various rupture times and at m = 3.

4. RESULTS AND DISCUSSION

4.1 Visual observation and metallography:

Dimensional measurement revealed that there was no change in outer diameter and thickness of the service

Table 4

Stress rupture properties of virgin and service -exposed main steam pipes of boilers .

Material	Sl No	Test Temp (K)	Stress (Mpa)	Rupture Time (hrs)	% EL	% RA
Virgin (Increased stress test)	1	823	200	46	32	56
	2	823	180	205	36	54
	3	823	150	960	36	56
	4	823	140	1440	25	71
	5	823	130	6048	Interrupted	-
	6	823	120	11088	Interrupted	-
Virgin (Increased temperature test)	1	963	65	77	13	71
	2	943	65	218	17	85
	3	923	65	672	15	80
	4	903	65	1673	10	18
	5	883	65	5032	10	210
Boiler D (Increased stress test)	1	798	180	170	53	80
	2	798	170	441	47	79
	3	798	160	432	54	80
	4	798	140	2688	53	72
	1	823	160	70	53	77
	2	823	150	242	52	77
	3	823	140	730	51	75
	4	823	130	1739	54	77
	5	823	110	5352	24	47
	1	873	120	121	58	80
	2	873	110	912	45	67
	3	873	100	1656	17	53
	4	873	90	2544	27	42
	5	873	80	5352	16	50
Boiler D (Increased temperature test)	1	943	65	466	43	51
	2	923	70	610	38	44
	3	903	75	2696	31	51
Boiler E (Increased stress test)	1	798	180	178	54	82
	2	798	170	533	55	82
	3	798	160	264	53	77
	4	798	140	1512	55	82
	1	823	160	103	56	80
	2	823	150	270	48	77
	3	823	140	462	38	83
	4	823	130	4104	35	65
	5	823	110	6216	45	76
	1	873	120	216	51	71
	2	873	110	556	27	77
	3	873	100	1288	27	67
	4	873	90	3905	42	71
	5	873	80	6672	Interrupted	-

Table 4

Stress rupture properties of virgin and service -exposed main steam pipes of boilers (continued)

Material	Sl No	Test Temp (K)	Stress (MPa)	Rupture Time (hrs)	% EL	% RA
Boiler E (Increased temperature test)	1	943	65	269	49	88
	2	923	70	740	52	88
	3	903	75	2940	44	84
Boiler F (Increased stress test)	1	823	110	11232	Interrupted	-
	2	823	130	1728	48	67
	3	823	140	658	46	68
	4	823	150	254	81	76
	5	823	160	54	49	74
	1	798	160	304	55	79
	2	798	170	284	48	76
	3	798	180	187	48	76
	1	873	80	4296	8	22
	2	873	90	2736	11	44
	3	873	100	928	30	44
	4	873	110	504	39	47
	5	873	120	238	50	49
Boiler F (Increased temperature test)	1	903	75	2952	18	36
	2	923	70	648	28	56
	3	943	65	418	17	28
Boiler G (Increased stress test)	1	823	110	6936	47	71
	2	823	130	744	55	71
	3	823	140	432	40	79
	4	823	150	161	25	56
	5	823	160	32	57	77
	1	798	140	864	52	74
	2	798	160	264	53	77
	3	798	170	163	59	76
	4	798	180	120	52	77
	1	873	80	5616	08	39
	2	873	90	1512	28	38
	3	873	100	672	38	48
	4	873	110	462	32	59
	5	873	120	76	58	67
Boiler G (Increased temperature test)	1	903	75	2769	20	44
	2	923	70	768	24	44
	3	943	65	336	32	48

Table 4

Stress rupture properties of virgin and service-exposed main steam pipes of boilers (continued)

Material	Sl No	Test Temp (K)	Stress (MPa)	Rupture Time (hrs)	% EL	% RA
Boiler H (Increased stress test)	1	823	190	24	23	78
	2	823	170	97	39	98
	3	823	150	264	37	75
	4	823	130	993	39	78
	5	823	110	5137	40	80
	6	823	90	9182	Interrupted	
Boiler H (Increased temperature test)	1	963	65	18	45	89
	2	943	65	198	38	79
	3	923	65	686	13	44
	4	903	65	1602	22	33
	5	883	65	5236	30	40
Boiler I (Increased stress test)	1	823	190	04	26	79
	2	823	170	69	38	84
	3	823	150	89	76	84
	4	823	120	1539	48	87
	5	823	100	5724	49	85
Boiler I (Increased temperature test)	1	963	65	39	63	80
	2	943	65	54	52	88
	3	923	65	312	33	78
	4	903	65	321	34	77
	5	883	65	2021	35	78
	6	873	65	4150	Interrupted	

exposed pipes. It seems that the pipes have not undergone any appreciable deformation during actual operating conditions. No evidence of localised and general corrosion/oxidation was observed on either external or internal surfaces. The hardness level of the virgin and service exposed main steam pipe of various boilers revealed (see Table.3) no significant variation in hardness values with exposure lives.

The microstructure of the virgin material mainly consisted of ferrite grains dispersed with carbides (Fig. 1). A typical micrograph of service-exposed main steam pipe is shown in Fig.2. No evidence of graphitization and creep damage in the form of cavitation and decarburisation was observed in any of the service-exposed main steam pipes. Therefore, it is clear that the virgin as well as those of the service exposed main steam pipes of all the boilers have hardly received any appreciable degradation from the microstructural point of view.

4.2 Mechanical properties

Room temperature as well as high temperature tensile properties as obtained from experiments are given in the results of Fig. 3. It is evident from these results that 0.2% proof stress (yield strength) and the UTS (ultimate tensile strength) values for the service exposed pipes show a decreasing trend with increasing temperature. However, % RA (reduction in area) and .% EL (elongation) are found to increase with temperature. This is the common trend observed for materials tested at elevated temperature /12,13/. Analysis of tensile data

Table5
Estimated rupture strength in MPa

Type of main steam pipe	Order of polynomial	Temperature, K	Time, hrs		
			tr =10,000	tr =30,000	tr =100,000
Virgin	m =3; C= 20	823	108	93.00	78.70
		773	119	103.00	86
		-	-	-	-
Boiler D	m =3 ; C= 20	773	142	128	115
		798	123	110	97
		823	106	93	79
		848	89	76	62
Boiler E	m =3; C= 20	773	143	130	116
		798	125	112	100
		823	107	94	79
		848	89	76	60
Boiler F	m =3; C= 20	773	144	131	119
		798	125	113	100
		823	108	96	83
		873	74	59	-
Boiler G	m =3 ; C= 20	773	138	127	114
		798	120	109	97
		823	103	92	81
		873	88	77	67
Boiler H	m = 3 ; C= 20	823	96	84	72
		823	99	86	73
		823	91	79	70
Boiler 1	m =3 ; C= 20	773	123	110	98
		798	106	95	84
		823	91	81	72
		848	78	70	6

revealed that there is some deterioration in yield stress (0.2 % Proof Stress), ultimate tensile strength (see Figs. 3a and 3b), % RA and %EL (see Figs3 and 3d) of the service-exposed main steam pipe of all the boilers compared to those of the virgin pipe, due to service exposure. However, these variations fall within the specified limits for similar grade of steels *viz.* 1Cr-1Mo-0.25V steels, as reported in literature /12/.

In the absence of discernible cavitation, stress rupture tests can be selectively used to assess the condition of components. One of the most widely used techniques for life assessment of components involves removal of samples and conducting accelerated tests at temperatures above the service temperature /8/. An estimate of the remaining life is then made by extrapolation of the results to the service temperature. Several uncertainties relating to the validity and application of the technique have been resolved in recent research projects /8/.

In the present investigation, long term rupture strengths were estimated with best fitted curves for third order polynomial. For different orders of polynomial, the average sum square error (ASSE) was estimated from the following equation:

$$ASSE = \Sigma (Y_{experimental} - Y_{estimated})^2 / n \quad (3)$$

where n is the number of data points. The third order polynomial was selected for estimation of rupture strength as there was no significant change in the average sum square error for higher orders.

Analysis of rupture data clearly indicates that the properties of the present steel are closely comparable to those of the virgin pipe (Fig. 4) suggesting no appreciable creep damage. The data points of the Stress vs LMP plots (Fig. 4) for all the service exposed materials fall within the ± 20% scatter band of the virgin material. The best fit curve for the virgin material has been extrapolated to a lower stress value beyond 65 MPa which is the allowable stress level of the service exposed main steam pipes of all boilers, for the purpose of life prediction (Fig. 4). Previous investigators /9,10/ estimate the remaining life of such ageing components by comparing the upper limit of the data scatter band in stress rupture tests with the ASTM and BSS mean data line. However, for life prediction in the present investigation, superimposition of the ISO-206 mean data line does not aid discussion on the influence of service exposure on the main steam pipe of the boilers. Therefore the experimental data for the virgin pipe was superimposed on the service-exposed data for the boilers for the purpose of comparison and life prediction of the service exposed pipes. At higher stress levels, creep rupture data fall outside the -20% scatter band limit of the virgin pipe which is indicative of creep properties inferior to the standard material. On the other hand, at lower stresses, the experimental data for the service exposed boilers approaches that of the virgin material (Fig. 4). This is a typical trend as observed with service exposed material. At lower stress levels, the service exposed main steam pipes of some of the boilers have superior stress rupture properties compared to that of the virgin pipe (see Fig. 4). In fact it is seen from Fig. 4 that at the allowable stress and operating hoop stress levels, the life of boilers D, E and F is even greater than that of the virgin material . This is mainly because stress rupture data usually exhibit a wide scatter of about ±20% around the mean data. Minor variations in chemical composition and section size of the test specimen may also affect rupture lives /12,13/. At lower stress levels, scatter is even higher as reported in literature /12,13/. Hence a slightly higher residual life of some of the boilers D, E and F as estimated in the present investigation is not unusual.

The remaining lives of all the service-exposed main steam pipes of all the boilers predicted at 65 MPa and at 823 K are shown in Fig. 4. At this stress level for all the service exposed pipes, the LMP value as read from the plot of stress vs LMP (Fig.4) is about 21000. Nevertheless, at the respective operating hoop stress level for various boilers, the LMP values as read from Fig. 4 vary in the range 21150 to 21300. At this value of LMP, one would expect a very long life. As a regular

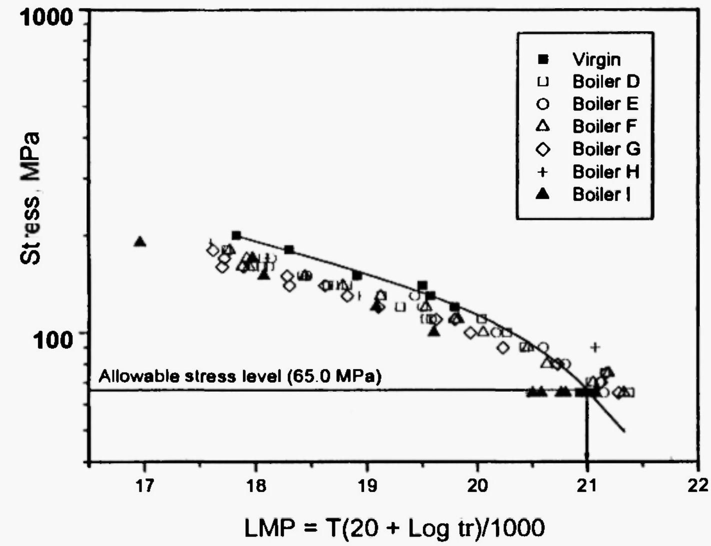

Fig. 4: Plot of stress Vss Larson- Miller Parameter (LMP) for virgin and various service -exposed boiler pipes.

procedure, an inspection life of >100,000 hours is recommended .

Since it is not always possible to give the precise residual life in view of some uncertainties including the over extrapolation, it should also be routine to make use of the following criteria to decide the serviceability (see Fig. 5) of such service exposed components /11/:

a) *Time margin* = $t_f / t_s > 3$
ii) *Stress margin* = $\sigma_{creep} / \sigma_s > 1.00$

where t_s = service life
t_f = rupture life at service stress (σ_s)
σ_s = service stress
σ_{creep} =stress for rupture corresponding to the service life

The higher the time margin, the better is the safety of operation for the service exposed materials. The values of the above margins as estimated from the stress rupture data in the present investigation for service exposed main steam pipes of boilers are summarized in Table 6.

So far as the remaining life at 823 K/ 65 MPa is concerned, it is possible to obtain a minimum life of > 100,000 hours for the service-exposed main steam pipes provided there is no evidence of localised damage in the form of surface cracks, cavitation or dents. Another check for safety of the service-exposed pipes in terms of residual life is recommended to be carried out after expiry of 50,000 hours of service life from the viewpoint of both economy and safety. Also during shut down of the plant, NDT (nondestructive) tests viz. dimensional (thickness and diameter) measurement, hardness measurement and *in-situ* metallography may be carried out to assess the condition of materials for

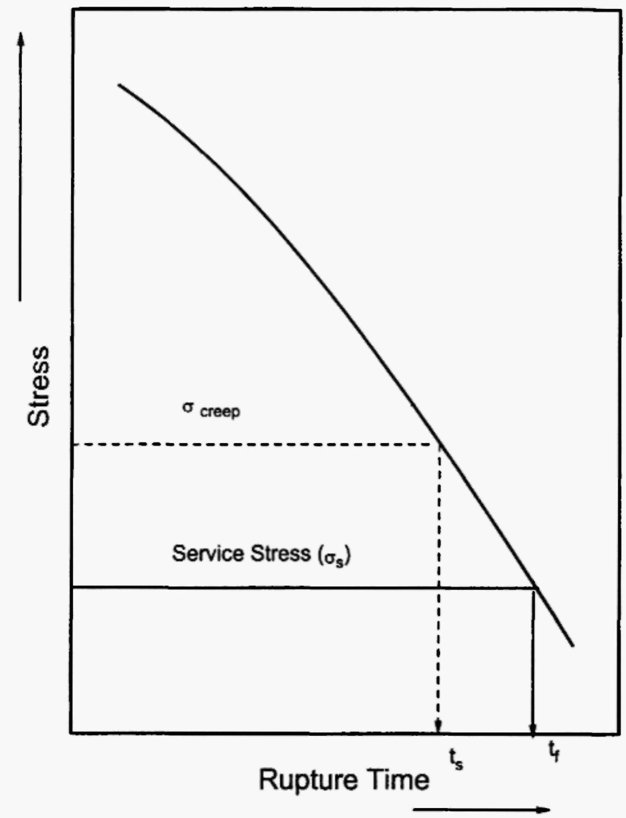

Fig. 5: Schematic representation for stress Vs rupture plot.

Table 6
Stress and time margin at 823 K

Type of Main Steam Pipe	Stress Margin at Operating hoop Stress levels	Stress Margin at Allowable stress level (65 MPa)	Time Margin at operating hoop stress levels	Time Margin at allowable stress level (65 MPa)
Virgin	-	-		-
Boiler D	1.14	1.41	5.12	6.05
Boiler E	1.09	1.41	5.4	3.44
Boiler F	1.27	1.41	5.58	7.17
Boiler G	1.26	1.41	5.63	6.30
Boiler H	1.09	1.41	8.9	3.99
Boiler I	1.09	1.41	8.03	3.56

their future serviceability. NDT examination of the weld joints at regular intervals during shut down of the plant is desirable as the microstructural examination of the weldment in some cases enables us to suggest the presence of defects like microporosities.

5.CONCLUSIONS

The following conclusions can be drawn:

(a) So far as the residual life at 823 K is concerned, it is possible to obtain a minimum life of about 100,000 hours for the service-exposed main steam pipes provided there is no evidence of localised damage in the form of surface cracks, cavitation or dents.

(b) Analysis of tensile data has revealed that there is some deterioration in yield stress (0.2 % Proof Stress), ultimate tensile strength, % RA and %EL of the service-exposed main steam pipes of all the boilers compared to those of the virgin pipe, but these variations are within the specified limits for similar grade of steels as reported in literature.

(c) The service-exposed main steam pipes of all the boilers appear to be in a reasonably good state of health. Another check for safety of the service-exposed pipes in terms of residual life is recommended to be carried out after expiry of 50,000 hours of service life from the view of economical and safety reasons. Also during shut down of the plant, NDT (nondestructive) tests viz. dimensional (thickness and diameter) measurement, hardness measurement and *in-situ* metallography may be carried out to assess the condition of materials for their future serviceability. NDT examination of the weld joints at regular intervals during shut down of the plant is desirable as the microstructural examination of the weldment in some cases reveals the presence of defects like microporosities.

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REFERENCES:

1. D. D' Angelo and A. Percivate, in: *Proceedings of International Conference on Creep,* Tokyo, Japan, 14-18 April (1986).
2. I.A. Klevtsov and Kh.A. Tallermo, *Teplo-energetika.*, **12**, 21 (1996).
3. T. Endo, *Int. J.. Press. Vess and Piping .*, **57** (1), 7 (1994).
4. M de.Witte, *Int. J. Press. Vess and Piping.*, 39 (1-2), 41 (1996).
5. Y D. Li, *Int. J. .Press. Vess and Piping.*, **69** (2),161 (1996).
6. I.. Klevtsov, H .Tallermo and R.A. Crane,. In: *Proceedings of International Conference on Plant Conditon & Life Measurement*, Vol I, Helsinki, Finland (6-8 June 1995): Pub-Technical Research Centre of Finland.
7. B. Wilshire, *Int. J.. Press. Vess and Piping.*, **39** (1-2), 73 (1989).
8. R. Viswanathan, R .Dooley and A. Saxena, in: *Proceedings of International Conference on Life Assessment and Extension,*Vol. II, Congress Centre The Hague/The Netherlands, 13-15 June (1988), p175.
9. A.K. Singh., A. J. Bagdasarian and V.K. Malhotra., in: NACE International, Houston, Texas, USA, (1994), p 21.
10. I.W. Goodall and R. A. Ainsworth, *CEGB Res.*, **16**, 34 (1984).
11. J. Gabriel Vanderschaeghe and G. Vigneron, in: *Proceedings of International Conference on Life Assessment and Extension,*, Vol II, Congress Centre The Hague/The Netherlands,13-15 June (1988), p 136
12. Data sheets on the elevated-temperature properties of 1Cr-1Mo-0.25V steel castings for steam turbine castings (ASTM A356/ A 356 M-9), NRIM creep data sheet, No. 31B, (1994).
13. S. Chaudhuri, Some aspects of creep behaviour of 2.25 Cr-1Mo steel, Ph.D. Thesis, I.I.T, Kharagpur, 1993.