RESIDUAL LIFE ASSESSMENT OF HIGH TEMPERATURE BOILER COMPONENT SUBJECTED TO CREEP AND FATIGUE

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ABSTRACT

Generally the reheater provided in the boiler of a thermal power plant is subjected to high temperature operation which results in usage factors / damages due to creep and fatigue during its lifetime. The creep damage is caused when the reheater is running at its operating pressure and temperature conditions and the fatigue damage is caused due to the number of start / stop during its service time like cold start, warm start and hot start conditions causing the temperature differences between the header and the inlet steam. The reheater outlet header after its service of 15 years clocking nearly 1.23 lakh hours can be assumed to have spent 70% of the time at the rated pressure and temperature conditions and balance at lower temperature conditions. But to be realistic, there will also be some amount of overloading of the component resulting in overshooting of temperature beyond the rated temperature. The fatigue damage is again caused by planned and unplanned shut down of the plant during the 15 years of operation. In order to assess the remaining life of the component, the individual damages due to creep and fatigue must be computed for estimating the cumulative damage. In one of the reheater headers, some minor cracks were observed in the stub to header weld (crotch) portion after running for nearly 15 years and some doubts were raised about the residual life of the component. The detailed analysis taking into account the operating conditions revealed that the cumulative damage is well within limits, which means that the component can be safely operated for 5 more years. The analysis also indicated that the cracks were not specific to creep. The recommendation was given in this regard to the customer and was validated after the component ran for 5 more years. The details of the analysis with the operating conditions are presented in this paper.

Keywords: *Residual Life Assessment, Fatigue Analysis using TRD,*

1. INTRODUCTION

During the regular residual life estimation study conducted through In Situ -metallography after the plant ran for nearly 15 years by one of the customer of BHEL, micro-cracks were identified in the header to stub joints in the Reheater Outlet Header. The customer was apprehensive about the use of this component for further period and was planning to retire the same. Subsequently when the views of BHEL was sought BHEL engineers visited site and made Visual inspection and carried out condition assessment study through, dimensional analysis, NDT checks and metallurgical replication. The findings of the study indicated that there was no creep damage identified in any of the location during the study and it was felt that there was no immediate replacement requirement of the Header. However the customer wanted to have a recommendation for further operation. Based on the above requirement of customer, further analysis was carried out by BHEL to assess the residual life of Reheater outlet header. The approach adopted in this study is to carry out the fatigue damage analysis, creep analysis and fatigue crack growth analysis on the component and to determine the percentage of the useful life of the component which has been already spent. The study was conducted only to ascertain the safe life of the header taking the possible damage conditions even though no creep damage had been identified in the earlier replication study.

2. APPROACH FOLLOWED

Generally the reheater provided in the boiler of a thermal power plant is subjected to high temperature during its operation which results in usage factors / damages due to creep and fatigue during its lifetime. The creep damage is caused when the reheater is running at the rated parameters of operating pressure and temperature conditions. The creep damage goes on accumulating with time. For estimating the creep damage, the number of operating hours at the corresponding temperatures is required. Any overheating beyond the rated temperature will bring down the creep life significantly. Likewise any operation below the rated condition will improve the creep life even though it may bring down the efficiency. Ideally speaking, the plant must be operated at the rated temperatures at all times, but due to operating difficulties, there will be some operations at below normal temperatures and some operation at above normal temperatures. From the feedback of the operating plant with certain realistic assumptions, the plant was operated for 70% of the time at 540°C which is the rated temperature, 20% of the time at 530°C and 10% of the time at 520°C. In addition, it can be assumed that there was overheating of the component at 550°C and the duration of the overheating in its life time of 15 years was 300 hours. The fatigue damage is caused due to the number of start / stop conditions like cold start, warm start and hot start wherein the component will be subject to thermal fatigue conditions due to differential temperatures between the incoming steam and the temperature of the component. The assessment of fatigue damage requires the data on the number of start / stop conditions and the corresponding temperature differentials. The start / stop conditions may be due to the planned or unplanned shut down of the plant during the 15 years of operation of the plant. Thus in order to assess the remaining life of the component, the individual damages due to creep and fatigue must be computed and added up to estimate the cumulative damage. For the reheater header in which some minor cracks were observed in the stub to header weld (crotch) portion, to estimate the remaining life of the component for taking a run /repair / retire decision, the data on the operating conditions were collected and the assessment was carried out using the well known TRD approach (German rules) and an approach from first principles which involved the construction of S-N curves. The details of the analysis and the results obtained are presented in this paper.

3. OPERATING CONDITIONS OF THE HEADER

The boiler was commissioned in 1984 and upto 1999, i.e. for a period of 15 years, the component was operated under the parameter conditions as shown in table 1. From the above data, extrapolations have been made to arrive at the operating hours upto 2005 i.e. for a period of 21 years and the extrapolated figures are also given in the same table.

Table 1 - Operating conditions of the boiler

Condition	15 years	21 years
Operating pressure	39 bar	39 bar
Operating temperature	540°C	540°C
Number of completed hours of service	1,23,000 hours	1,72,200 hours
Number of completed hours of service at540°C (70 %)	86,100 hours	1,20,540 hours
Number of completed hours of service at 530°C (20%)	24,600 hours	34,440 hours
Number of completed hours of service at 520°C (9.75 %)	12,300 hours	17,220 hours
Number of hours at overloaded condition at 550°C (0.25%)	300 hours	420 hours
Number of cold starts	19	27
Number of warm starts	41	58
Number of hot starts	79	119

3.1 Fatigue Analysis using TRD Rules

The TRD rules are the German standards for the design, construction and evaluation of power plant components. For the present analysis, the approach given in TRD 301 and TRD 508 standards are employed [1]. The standard requires the determination of mechanical stresses like pressure stress and thermal stress and assess the combined stress from the individual components after multiplying them by suitable stress concentration factors. After determining the combined stress in the component for a given operating condition, the allowable cycles for this stress is read out from a master curve and knowing the actual number of cycles, the life fraction can be calculated. The calculations are as shown in table 2.

Table 2 - Analysis of life fraction due to fatigue up to year 1999

	Cold start	Warm start	Hot start
Differential temperature	100°C	75°C	50°C
Operating pressure	3.83 MPa	3.83 MPa	3.83 MPa
Maximum stress	900.4 MPa	686.2 MPa	486.3 MPa
Maximum alternating stress	2167.7 MPa	1259.0 MPa	632.6 MPa
Allowable cycles from TRD curve	214	955	8646
Actual number of cycles	19	41	79
Usage factor due to fatigue	8.88%	4.29%	0.91%

The above analysis has been extended for 21 years i.e. up to the period 2005 and the calculations are as given

	Cold start	Warm start	Hot start
Differential temperature	100°C	75°C	50°C
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Maximum stress	900.4 MPa	686.2 MPa	486.3 MPa
Maximum alternating stress	2167.7 MPa	1259.0 MPa	632.6 MPa
Allowable cycles from TRD curve	214	955	8646
Actual number of cycles	27	58	119
Usage factor due to fatigue	12.62%	6.07%	1.38%

in table 3.

Table 3 - Analysis of life fraction due to fatigue up to year 2005

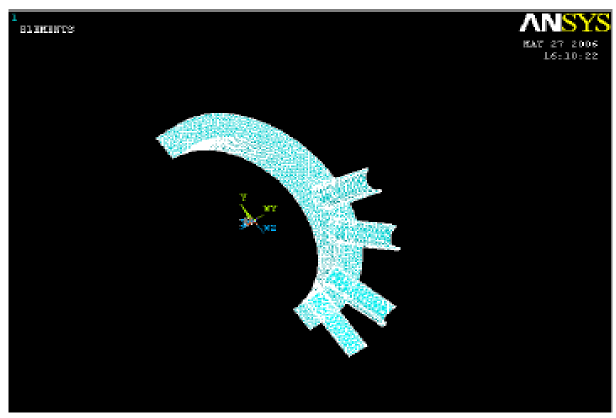
Thus it can be seen that the total life fraction consumed due to fatigue is only 14.08% for the period up to 1999 and 20.07% for the period up to 2005. The tables also show that the maximum usage factor due to fatigue is caused by the cold starts where the differential temperature between the incoming steam and the temperature of the header is the maximum at 100°C. When the differential temperature is reduced to 50°C from 100°C, the usage factor decreases by nearly 89%.

3.2 Fatigue Analysis using S-N Curve Method

In order to verify the calculation methodology, the fatigue analysis was also carried out through an alternate route viz. to calculate the peak stresses in the component using finite element method, and to determine the fatigue usage factor from a S-N curve constructed from first principles. For determining the maximum stress in the component caused by the pressure and differential temperatures, finite element analysis has been performed using ANSYS package. The component taken for the analysis is as shown as combinations of finite element. As the component has tubes at a pitch of 150 mm and assuming symmetry conditions, a segment of 75 mm as shown in figure 1 is considered for the analysis. The thermal transients between the header and the tubes will be felt only to a distance of 100 mm and any disturbances beyond that distance will not affect the present analysis and hence the analysis is carried out with a tubes projecting for a distance of 100 mm in the radial direction.

Figure 1 - Element plot of Reheater outlet header - employed in the finite element model.

As the thickness of the header is 60 mm, a full three dimensional analysis has been performed in order to assess the transient thermal stress in the thickness direction. The finite element analysis was performed using eight noded brick elements and the mesh employed for thermal analysis was retained for stress analysis also. The thermal analysis was performed first with the initial temperature of the component being 280°C, 375°C and 490°C corresponding to cold start, warm start and hot start conditions respectively. The temperature of the inlet steam corresponding to cold start, warm start and hot start are assumed as 380°C, 450°C and 540°C respectively. When the steam is entering the header, the thin layer of the component will be instantaneously raised to the temperature of the inlet steam and this brings up the temperature differentials in the component. The transient thermal analysis was



performed for this condition and the results were stored in a file. The thermal results are as shown in figure 2.

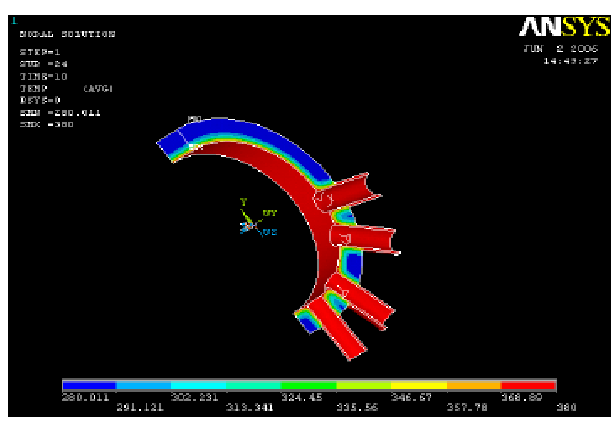


Figure 2 - Thermal results obtained using finite element analysis.

Subsequently, the stress analysis was performed on the component with the thermal inputs and the pressure inputs. The symmetry boundary conditions were assumed in the analysis and some additional conditions were imposed to prevent the rigid body movement of the component. The Von-Mises stress results of the component are given in figure 3.

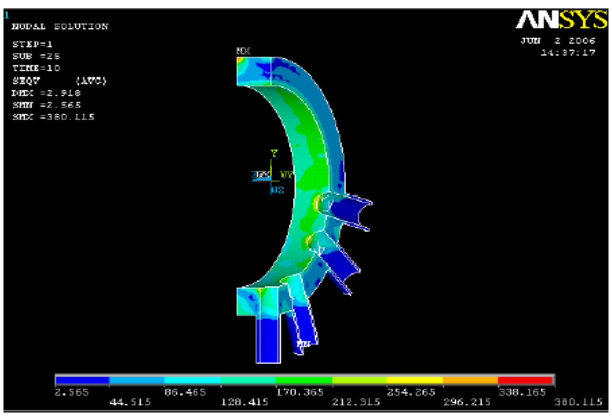


Figure 3.- Von-Mises equivalent stress from the finite element analysis

The maximum von Mises stress results for the three conditions are as given in the table 4.

Table 4 - Peak stresses from finite element analysis

Type of start	Steam pressure, bar	Steam temp, °C	Header O D temperature , °C	Maximum Von-Mises equivalent stress, *MPa*
Cold	12	380	280	368.54
Warm	18	450	375	272.85
Hot	36	540	490	158.15

The construction of the S-N curve was carried out using the procedure as given in reference [2]. The construction requires the determination of factors corresponding to the surface factor, size factor, reliability factor, temperature factor, notch sensitivity factor and any other miscellaneous factor [3]. Taking suitable values for the above, the S-N curve is constructed and the equation for the curve is given as

$$S = 707.6 - 114.07 * \log(N) \qquad (1)$$

From this equation, the maximum allowed cycles for a given stress level is calculated and knowing the actual number of cycles in each stress level, the usage factors are calculated. The values are as given in the table 5.

Type of start	Max stress ,MPa	Completed cycles	Allowable cycles	Life fraction (%)
Cold	368.55	19	938	2.03
Warm	272.85	41	6475	0.63
Hot	158.18	79	65541	0.12

Table 5 - Analysis of life fraction up to year1999.

The analysis has been extended up to year 2005 and the results are as given in the following table.6

Type of start	Max stress ,MPa	Completed cycles	Allowable cycles	Life fraction (%)
Cold	368.55	27	938	2.88
Warm	272.85	58	6475	0.90
Hot	158.18	119	65541	0.18

Table 6 - Analysis of life fraction upto year 2005.

It can be seen that the figures obtained are much less than the corresponding figures obtained using TRD approach. It shows that the TRD approach is very conservative in its estimation. Again, it can be seen that the maximum life fraction is consumed for cold start condition and when the temperature differential is reduced by 50°C, the life fraction reduces by 93.7%.

3.3 Creep Analysis using TRD Rules

In the approach, the creep stress vs. log time diagram is constructed for the material corresponding to 10^4 -10^5 and 2 * 10^6 hours of creep life. A straight line is then fitted to the three points and taking this as the master curve, the creep life fraction is calculated. The following table presents the expended life fraction up to year1999.

Table 7 - Analysis of life fraction due to creep up to year 1999.

Pressure, bar	Nominal stress, MPa	Temperature °C	Completed hours	Allowable hours	Expended life fraction (%)
39	41.29	540	86100	696741	12.36

39	41.29	530	24600	3673936	0.67
39	41.29	520	12300	51961315	0.02
39	41.29	550	300	317685	0.09

The extrapolated figures up to year 2005 is as given in the following table 8

Table 8 - Analysis of life fraction due to creep up to year 2005.

Pressure, bar	Nominal stress, MPa	Temperature °C	Completed hours	Allowable hours	Expended life fraction (%)
39	41.29	540	120540	696741	17.30
39	41.29	530	34440	3673936	0.94
39	41.29	520	17220	51961315	0.03
39	41.29	550	420	317685	0.13

It can be seen that the creep usage factor is 13.15% and the maximum usage is when the plant was operating at 540°C. However, it can be seen that a relatively small overheating to 550°C for 300 hours has produced disproportionately large amount of usage factor. The analysis using TRD rules reveals that the usage factors for fatigue and creep are 14.08% and 13.15% for the period ending 1999. The usage factors for fatigue and creep for the period ending 2005 are 20.07% and 18.4% respectively. Even assuming a factor of safety of 2, the cumulative usage factor for fatigue and creep works out to 38.47% for the period ending 2005. Thus it becomes clear that the cracks observed are not specific to creep or fatigue. In order to further evaluate the cracks at the location of interest, a non destructive test and a replica analysis were carried out in the site periodically every 2 years. From the following observations, it can be surmised that the cracks were definitely not specific to creep.

1. The cracks were intergranular and confined to the stub welds only.
2. The cracks disappeared on grinding by about 0.5 mm to 1 mm.
3. The cracks did not have typical appearance of being creep induced, since there were no creep voids around or at the tips of these cracks.
4. The cracks were not strictly parallel.
5. The cracks did not grow during the regular observations conducted at the location of interest
6. MPI revealed the cracks only at micro polished areas
7. Structures at the parent metal, HAZ of stub welds, as well as butt welds did not show creep cavitation damage.
8. Some small bits of welds removed when examined under light microscope did not show any crack / creep pore

Thus, it can be safely surmised that the cracks which were observed in the crotch portion of the header to stub weld joint, were not specific to creep and will not propagate to critical level in the next 5 years. Thus the above detailed analysis which has taken into account the operating conditions revealed that the cumulative damage due to creep and fatigue is well within limits, which means that the component can be safely operated for 5 more years. The analysis also indicated that the cracks were not specific to creep. The recommendation was given in this regard to the customer and was validated after the component ran for 5 more years.

4. CONCLUSIONS

For the specific component on hand with known levels of operating conditions, the usage factor for fatigue and creep have been calculated using TRD rules and the combined usage factor for the period up to year 2005 works out to 38.47%. This level is well below the level of 50% and hence it can be surmised that the component can be operated safely for some more time. The independent fatigue damage analysis through the determination of peal stresses using FEM and the fatigue life from the S-N curve shows that the expended fatigue life is much lower in the component. The crack which was observed in the crotch portion of the shell to stub weld was found to be not specific to creep and will not propagate to critical level in the next 5 years. The findings of the analysis were validated through metallurgical evaluation using In-Situ Replication principle at the point of interest at various time intervals to ensure that the initially observed cracks did not propagate further.

5. REFERENCES

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