BOILER FEED WATER PUMP SHAFT LIFE ASSESSMENT THROUGH RESIDUAL STRESS MEASUREMENT

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ABSTRACT

In recent times frequent Boiler Feed Pump (BFP) shaft failures have been reported at various thermal power stations within India. Most of these were found to be due to reverse bend fatigue loading, with crack being initiated at the key way under the thrust pad. In BFP shaft material deterioration (damage) gets accumulated due to severe operating conditions. This can conveniently be monitored by the surface residual stress variation with time, using X-ray diffraction technique. In the present investigation residual stress measurements were performed periodically on flat specimens of BFP shaft steel which were subjected to reverse bend fatigue. The measurements were done at different locations in order to identify the exact region of maximum damage. A master curve between the residual stress ratio and the cycle ratio has been generated and its application to remaining fatigue life assessment of the component has been discussed.

KEYWORDS

Residual stress, boiler feed pump shaft, reverse bend fatigue, residual fatigue life assessment

INTRODUCTION

Current research in power plant industry is highly oriented towards remaining life assessment of critical components. Most of the thermal power plants are under operation for the last ten to fifteen years since their commissioning. In order to meet the increasing power supply demands they are being operated under severe operating conditions, like operating continuously at their full rated capacities. Such operations cause deteriaration (damage) in materials used for various critical components of the power plant. Boiler feed pump (BFP) shaft is one such component, in which the deteriaration gets accumulated as a result of the increasing start/stop frequency and its operation in the low flow rate range Yoshiharu Ueyama et al., 1991). Among various pumps delivered to a power plant, BFP is the most important auxiliary component which receives maximum pressure of about 20 MPa and temperature of about 175°C. These pumps are designed for an operating speed in the range of 5200-5400 rpm. Tough these pumps do not fail catastrophically, their failure would certainly cause a shut-down. Under these conditions it becomes essential to check the pump for its safe operation against the severe operating conditions, employing non-destructive methods.

In the recent past a number of BFP shaft failures have been reported at various thermal power stations within India. Majority of the failures were found to occur in the shafts with shrunk-fitted thrust pads. In these cases, the thrust collar is heated to a temperature of about 225-250°C to facilitate the assembly. Laboratory investigations carried out on some of these shafts have revealed that the failures were mainly due to reverse bend fatigue (Prasad and Rajanna, 1994) and the crack was found to initiate at the keyway under the thrust pad. In a few cases, a build up of tensile residual stress has also been observed at the keyway. These failures have provided a basic insight into the nature of fatigue damage accumulation in BFP shafts.

Residual stresses (σ_r) are those which remain within the material under no action of any external force. These could arise due to the heat treatment procedures adopted or the machining/fabrication processes employed (Cullity, 1956). In general majority of these processes result in a compressive residual stress at the surface, which is beneficial from the point of view of delaying the crack initiation. However, this compressive residual stress is known to decrease with fatigue cycling (Frost et al., 1974). A tensile residual stress can be a pre-cursor for crack initiation. This was confirmed in thermal fatigue damage assessment of CrMoV cast steel where in the crack was found to initiate when the surface residual stress approaches zero or a slightly tensile value (Jayaraman et al., 1994).

It is known that crack could initiate from a location at the surface where the damage due to fatigue is maximum. Many investigators have made attempts to assess the condition of the surface for crack initiation by non-destructive techniques. In some of these attempts, X-rays were found to be useful because of their shallow penetration (about 20 μm) and were used to detect conveniently the accumulated damage in materials/components subjected to fatigue loading (Kodama, 1971; Neff, 1981; and Ohuchida et al., 1972). The measured residual stress and the X-ray diffraction line broadening were taken to represent the macroscopic and submacroscopic material parameters. Changes in these parameters have been correlated to the accumulated fatigue damage. Investigations related to some of the thermal power plant components include, thermal fatigue damage assessment in High Pressure (HP) steam turbine rotor (Jayaraman et al., 1994) and fatigue damage assessment of BFP pumps (Yoshiharu Ueyama et al., 1991). These observations have indicated the possibility to develop a method, involving measurement of surface residual stress for accumulated damage assessment in materials.

The present investigation aims at developing a method to assess the remaining fatigue life of BFP shafts by carrying out residual stress measurements on specimens prepared from the steel and subjecting them to reverse bend fatigue loading.

EXPERIMENTAL PROCEDURES

Material selected for the present investigation was a X20Cr13 grade boiler feed pump shaft steel. Chemical composition of the steel as obtained by wet analysis is given in Table 1. Table 2 shows the room temperature mechanical properties. Flat reverse bend fatigue test specimens were prepared as per the drawing shown in Fig. 1. Fatigue tests were conducted at room temperature on a Schenck reverse bend fatigue test machine employing 20 Hz frequency. Completely reversed stress amplitudes, ranging from 300 to 600 MPa, were employed in the testing. The S-N curve obtained is shown in Fig. 2. The endurance limit was found to be about 310 MPa. The tests were interrupted periodically for surface residual stress measurements using a portable Rigaku X-ray stress analyser. The stress measurements were performed at the gauge portion of the test specimen over an X-ray irradiated area of about 20 mm in width by 2 mm in the length direction, as indicated in Fig. 1.

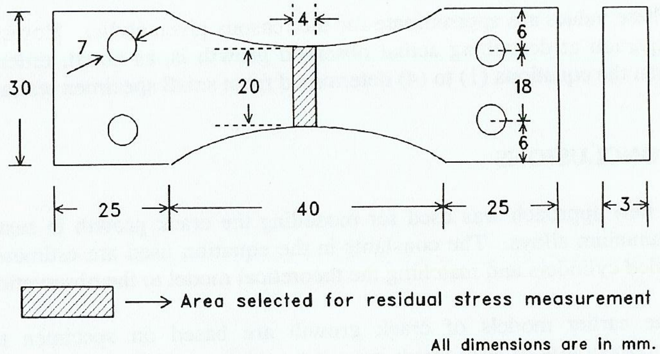

Fig.1 Flat reverse bend fatigue test specimen drawing indicating the area selected for residual stress measuremnt

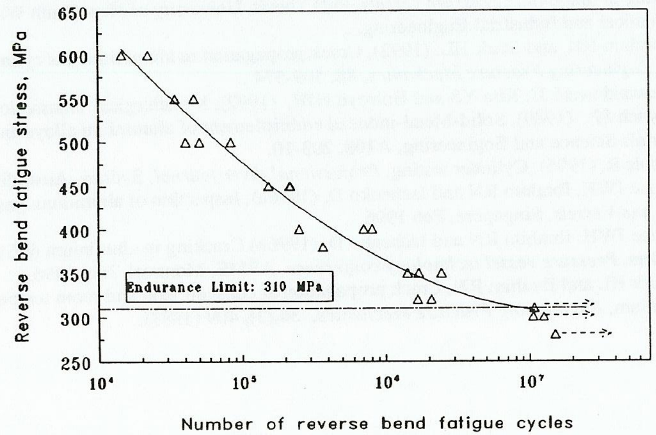

Fig. 2 S-N Curve

Table 1 Nominal Chemical Composition of the BFP Shaft Steel Investigated

C	Cr	Mn	Ni	Mo	P	S	Si
0.17	11.75	0.65	0.29	0.31	0.031	0.011	0.31

Table 2 Mechanical Properties of the BFP Shaft Steel Investigated

PROPERTY	VALUE
Tensile strength (MPa)	780
Yield strength (MPa)	550
Elongation (%) min.	19
Reduction in area (%) min.	52
Brinell hardness (BHN)	218
Charpy Impact Value (J)	65

RESULTS AND DISCUSSION

Variation in the measured residual stress (σ_r) as a function of number of fatigue cycles (N) is shown in Fig. 3, for tests carried out at 300, 400, 450, 500, 550 and 600 MPa stress levels. In all the cases, the σ_r has varied linearly with N. It may be noted that the initial compressive surface residual stress (of about 350 MPa) has increased to almost zero for tests performed using stress amplitudes above 450 MPa. However, it was not the case with those tests performed using stress amplitudes lower than 450 MPa. This was attributed to the fact that for low stress level testing the fatigue damage becomes microscopic (as in high cycle fatigue) and the damaged area can not be easily located. On the other hand, the damage will be more or less uniform (as in low cycle fatigue) through out the gauge portion of the test specimen, in case of the tests performed with stress levels close to the yield strength. This has been verified by carrying out additional fatigue tests on similar flat samples, using stress levels of 350, 400 and 450 MPa and measuring the residual stresses at ten different locations, each with an area of about 10 mm in width by 4 mm in length direction of the specimen. A schematic showing the selection of measurement locations on the test specimen is shown in Fig. 4.

A significant variation in the residual stress was found at one or two locations only, for tests conducted at 350 and 400 MPa, while for the test conducted at 450 MPa it was found to vary significantly for almost all the ten locations. The rate of σ_r variation with N was found to be different for different locations, in all the cases. However, the differences were marginal in case of the tests performed using 450 MPa. Results obtained from locations, at which significant variations were noticed, are shown in Fig. 5, Fig. 6 and Fig. 7 for 350, 400 and 450 MPa test conditions, respectively. These observations suggest that residual stress measurements have to be carried out at various locations in order to identify the exact region

at which the damage is maximum. This would be necessary to develop a master curve or equation for remaining fatigue life assessment of any component. In an earlier investigation (Yoshiharu Ueyama et al., 1991) a master curve showing the variation of residual stress ratio (σ_r/σ_{r0}) with the cycle ratio (N/N_f) has been generated. Similar curve has also been developed in the present investigation and is shown in Fig. 8 for each stress level employed. While σ_r indicates the residual stress value measured at any instant, σ_{r0} represents the value before the specimen was subjected to fatigue. N is the number of fatigue cycles at the measurement time while N_f indicates the number of cycles to failure.

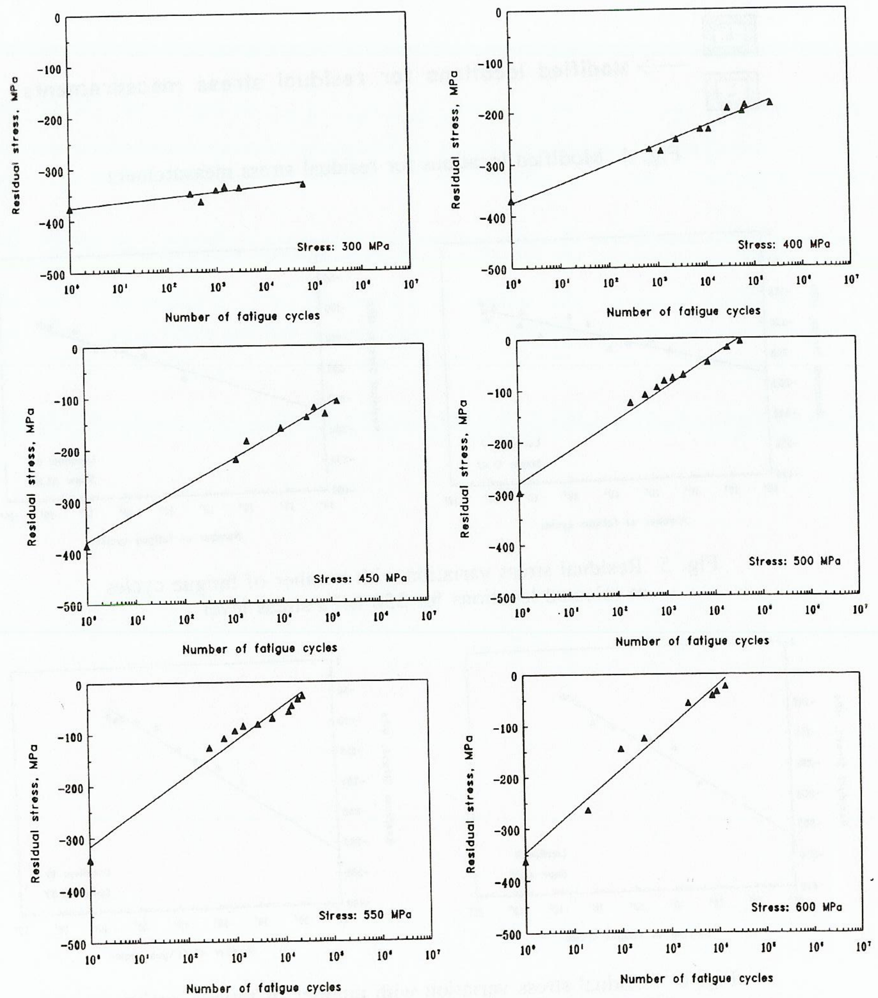

Fig. 3 Residual stress variation with number of fatigue cycles for tests carried out at different stress levels

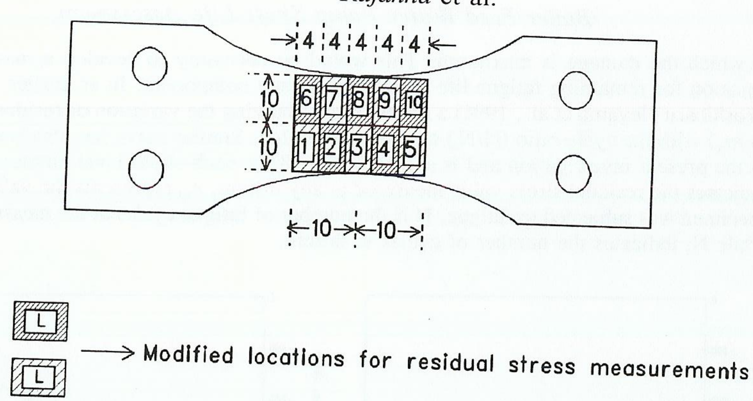

Fig. 4 Modified locations for residual stress measurement

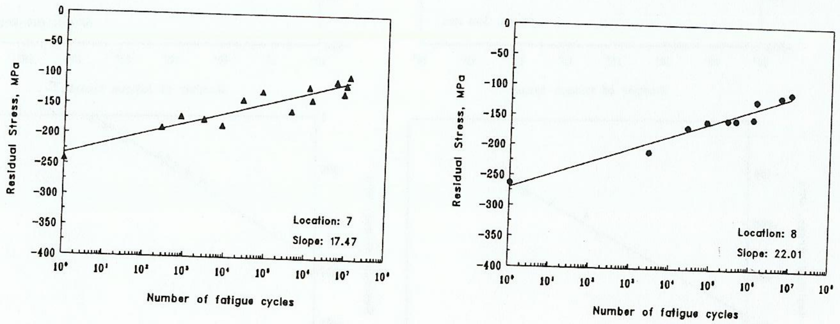

Fig. 5 Residual stress variation with number of fatigue cycles at selected locations for 350 MPa stress level

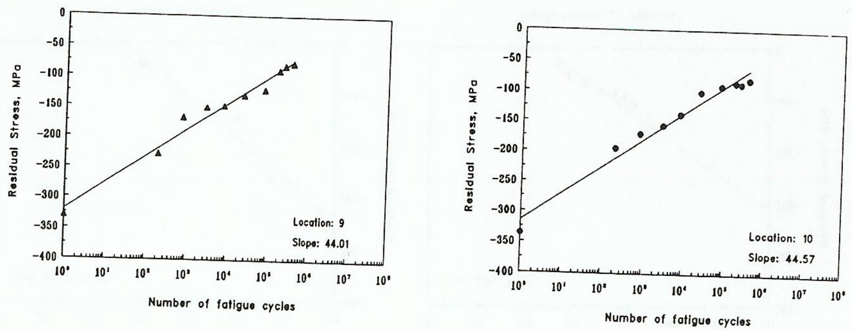

Fig. 6 Residual stress variation with number of fatigue cycles at selected locations for 400 MPa stress level

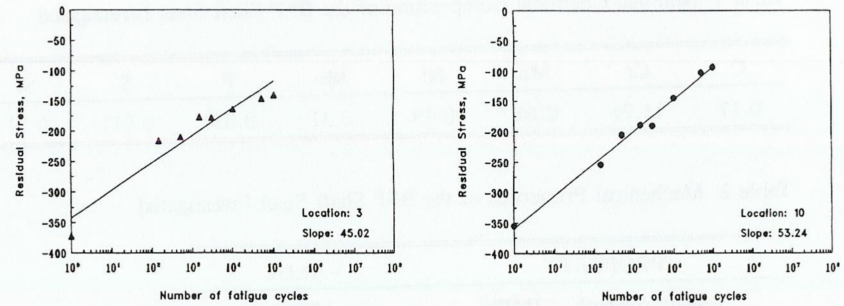

Fig. 7 Residual stress variation with number of fatigue cycles at selected locations for 450 MPa stress level

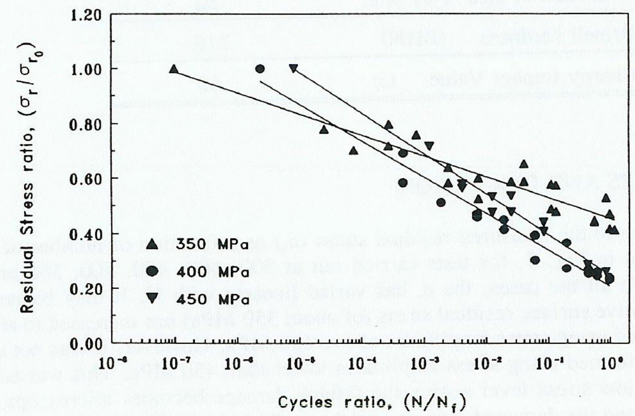

Fig. 8 Variation in residual stress ratio with cycles ratio for 350, 400 and 450 MPa stress levels

For remaining life prediction of the component residual stress measurement has to be carried out at the damage detecting location, prior to operation. At the start of operation, the total number of revolutions, or operation time, has to be recorded as an operational history. The measurements will have to be repeated at the same location during the subsequent in-service inspection. The resultant σ_r/σ_{r0} value can then be substituted into the master curve (Fig. 8) in order to determine the corresponding cycle ratio (N/N_f) which inturn gives the life consumption ratio. The remaining life, N_r, of the component at that particular instant can then be obtained from the following equation.

$$N_r = N * (1 - N/N_f) / (N/N_f)$$

For life prediction of the in-service component, surface residual stress measurements have to be carried out on the shaft at different locations around the key-way location under the thrust pad, from which crack was found to initiate in most of the reported failures of BFP shafts.

CONCLUSIONS

The accumulated fatigue damage in boiler feed water pump shaft was conveniently monitored through surface residual stress measurement using X-ray diffraction technique and a master curve has been developed for remaining life assessment of the in-service shafts.

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