

INFLUENCE OF SHOT PEENING ON CORROSION PROPERTIES OF STEAM TURBINE BLADING STEEL

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ABSTRACT

12% Chromium steels are extensively used as steam turbine blading material due to their good corrosion resistance and moderately high strength. These steels are however susceptible to environmentally assisted cracking in chloride containing media. Controlled shot peening is a pre-stressing technique conducted to impart a residual compressive stress which considerably increases the fatigue life of the components.

Corrosion fatigue and stress corrosion studies carried out on 12% Cr turbine blading steel on virgin and shot peened material, after optimizing the shot peening parameters have yielded highly encouraging results.

Virgin and shot peened samples were polarized anodically for observing potentiodynamic characteristics in 1 N H₂SO₄. Samples were also subjected to pitting scan for observing the localized corrosion characteristics in chloride containing media. The formation of a passivating film becomes complex when the surface has been altered by shot peening in comparison to mirror finish polished surface. Interesting observation has been made in the present work that the pitting susceptibility of the material in chloride environment is not affected adversely inspite of surface modification brought about by shot peening as compared to virgin material.

KEY WORDS - Fatigue, corrosion fatigue, SCC, shot peening, potentio dynamic, cyclic polarisation, chloride media.

INTRODUCTION

Turbine vapour, in fact does not comprise only of pure steam, but invariably includes various impurities such as oxidized scale from super heaters, impurities contained in boiler feed water and contamination due to boiler cleaning agents. In low pressure turbine, where the first condensate forms, the zone of condensation shifts according to load conditions thereby producing deposit free and deposit coated areas on the blade (1).

In the presence of deposits on the blades, the first water droplets are not able to dissolve all the precipitated salts but just moisten these salts. This results in building up of localized region with high salt concentration. Added to this, if there is condenser leakage and chloride enters the system, HCl is formed as a result of hydrolysis. Due to low distribution coefficient of HCl, it gets accumulated in the first water droplets thus lowering the pH. These droplets are very aggressive since there is a combination of high salt concentration and low pH value. This give rise to formation of pit that is the starting point for corrosion failure. These blades are reported to have failed due to fatigue, SCC and corrosion fatigue (2,3).

Fossil fuel fired power generating stations have traditionally been built with an assumed nominal economical life of about 25-30 years. The implicit expectation is that these units could be replaced only at the end of this period. But, such an expectation is hard to be realized especially in a power starving country like India, where installed capacity is far below the demand level. Even in industrially advanced countries such expectations have not been realized due to various other reasons. Depending upon actual operating conditions, the material properties of the power generating components degrade as a function of service life due to one or more of the time dependant material damage mechanisms such as creep, fatigue, corrosion, erosion, wear and embrittlement etc.,

Studies have indicated that almost 50-80% of the components such as gears, turbine blades and other mechanical components fail due to fatigue (4). Several surface treatments have been employed by the industries to improve the fatigue properties of the material. The common ground for different technology used is to change the fatigue strength by means of modifications in both the microstructure and the residual stress field in the surface layer of the material. Investigations carried out by park (5) revealed that shot peening on steam generator tubing in a nuclear power plant resulted in retarding the crack initiation and growth.

In the present study focus has been on the applicability of shot peening. Shot peening of the material causes plastic deformation at its surface which introduces compressive residual stresses into the material. Experiments were conducted by peening block samples using different shot diameters and pressure combinations. Stand off distance of 140mm and nozzle dia of 60mm was used. Shot peening parameters were optimized with respect to surface finish and residual stresses. Residual stresses were measured using x-ray diffraction method based on Bragg's law. It has been found that the depth of peening is directly proportional to the shot diameter and is of the order of 50% of shot diameter.

FATIGUE BEHAVIOUR

Studies carried out earlier on virgin and shot peened samples in air and in 3.5% NaCl solution showed that the fatigue limit for 10^7 cycles is 36kg/mm^2 in case of unpeened samples and 44 kg/mm^2 (Fig 1) for peened samples. Corrosion fatigue resistance was found to be 17 kg/mm^2 & 24 kg/mm^2 (Fig 2) for unpeened and shot peened samples respectively.

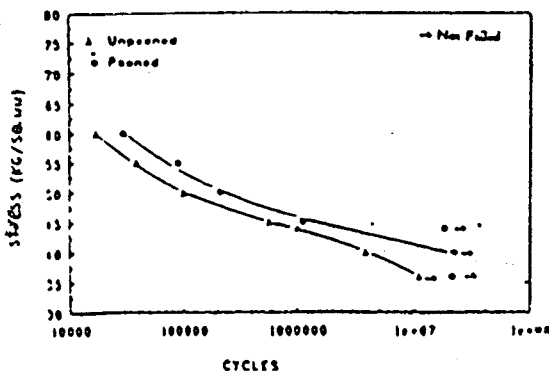


Fig.1 Cycles to failure with varying stress (air)

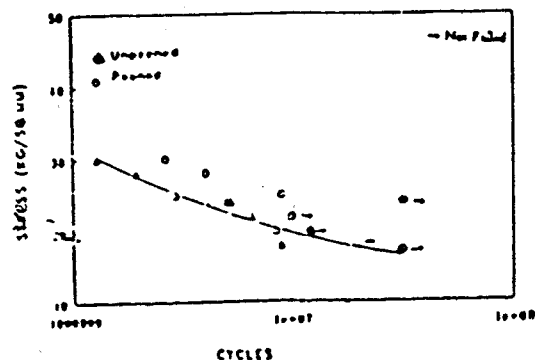


Fig.2 Cycles to failure with varying stress (3.5% NaCl)

SCC BEHAVIOUR

Similarly stress corrosion cracking studies in 3.5% NaCl with U bend specimen for various tempering temperatures were carried out. Tempering temperature of 675°C was found to give optimum SCC resistance (Fig 3) which is further improved by about three times by shot peening (6).

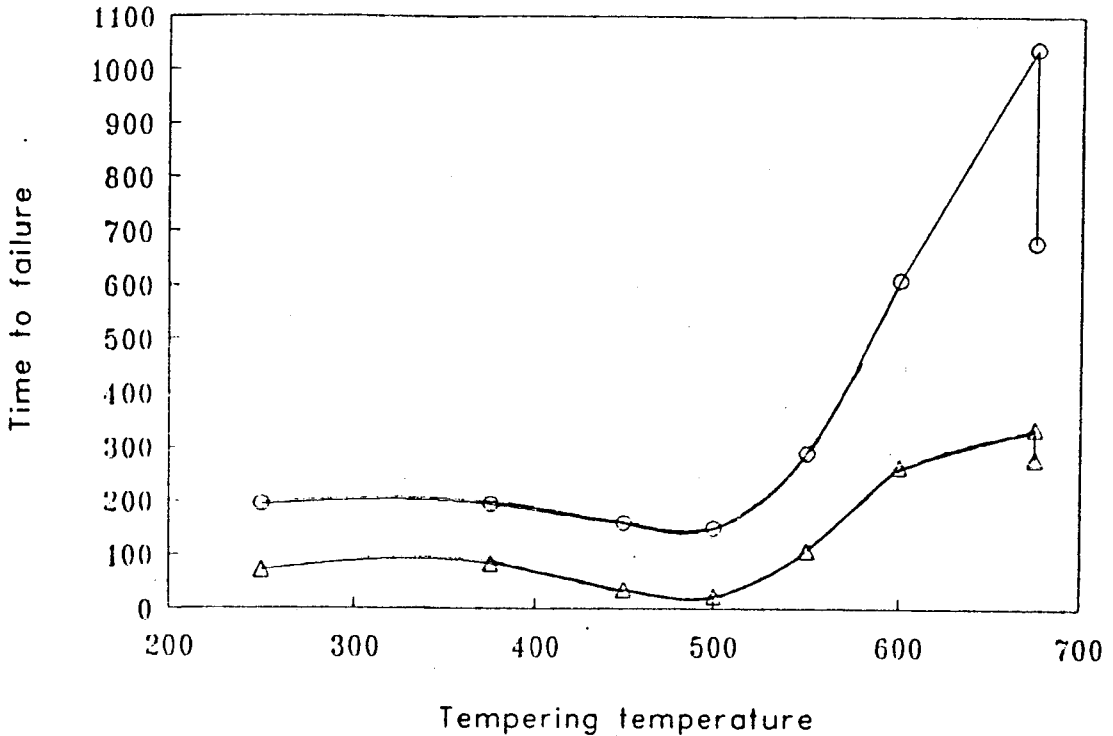


Fig.3 Time to failure of U-bend specimen subjected to different tempering temperatures

ELECTRO CHEMICAL BEHAVIOUR

The aqueous corrosion fatigue phenomena of an alloy steel system can be analyzed to be governed by at least three major factors. They are the stress field, the metallurgical nature of the steel and the environment. For a systematic understanding of the environmental effect, its influence needs to be isolated and studied. This is justified by the fact that for a given level of stress for chosen steel, the effect of environmental factor can be easily resolved. In fact, what is apparently a purely mechanical fatigue, in the absence of an environment, it turns out to be corrosion fatigue under the influence of the former. Corrosion phenomena by itself, originates from the electrochemical influence across the steel-environment phase boundary. Since this phase boundary is electrochemical in nature, it then becomes necessary that, the electrochemical behavior of steel is studied initially in the absence of applied stress initially and then under the applied stress, or, in-situ, in order to gain knowledge of the underlying phenomena.

Hence in order to understand the environmental characteristics of 12% chromium steel in terms of its corrosion behavior, the steel was first examined in 1.0NH₂SO₄ medium by potentiodynamic anodic polarization technique. Then the steel behavior was further investigated in 1.0% NaCl and 3.5% NaCl, to explore the susceptibility of the steel towards localized

corrosion phenomena using cyclic potentiodynamic polarization technique. The electrochemical investigation was also carried out with shot peened surface conditions so as to resolve the influence of the surface modifications/treatments in the above aqueous media. The results obtained involving the electro chemical study are presented and discussed in the present context.

THE EXPERIMENTAL SET UP

The electrochemical polarization of 12Cr steel was carried out in 1.0N H₂SO₄ medium using potentiodynamic anodic polarization technique. The experiments were performed in a specially designed cell, having provisions for

- a) Angular sideways insertion of reference probe tip, very close towards the centre of the immersed circular test specimen.
- b) Insertion of two parallel spectrographic grade graphite counter electrodes.
- c) Central insertion of test specimen of Teflon encapsulated circular test specimen of 1.0sqcm effective area.
- d) Gas purging tube that could reach the bottom of the cell.
- e) Gas escape bubbler.

The electrochemical polarization control of the test cell was achieved using a princeton applied research model 270 versastat. This is a fully computerized equipment that functions in Galvanostatic or Potentiostatic mode as the case may, driven by a very versatile corrosion software, incorporating advanced versions of corrosion rate measurement techniques.

In the present investigation the cell probes were connected to the equipment and the experiments were carried out by automatic parameter control through the computer. Initially, the test specimen corrosion potential at $28 \pm 2^\circ\text{C}$ was first measured for 5 minutes, under E_{corr} verses time mode. After storing this data, we immediately switched over to Potentiodynamic Technique mode and performed our experiments. The various data stored from different specimens were recalled, analysed, edited and presented in this investigation.

a) The potentiodynamic anodic scan in 1.0NH₂SO₄ medium

The free corrosion potential E_{corr} of the 12% chromium steel in 1.0NH₂SO₄ at 28°C was -523 20mV. The potentiodynamic scan was initiated at -800mV, about 300 mV cathodic to observed E_{corr} , and was scanned @ 1mV/sec till 1600mV was reached. As the scan progressed, we observed that the steel demonstrated a peak followed by a broader and lower current region subsequently followed by sharp increase in anodic polarization of current. The actual electro chemical behaviour of the steel in terms of applied potential and logarithm of the observed current for virgin and shot peened material is shown in Fig. 4. These scans resemble very well with the standard potentiodynamic scans obtained for type 430 stainless steel (7,8).

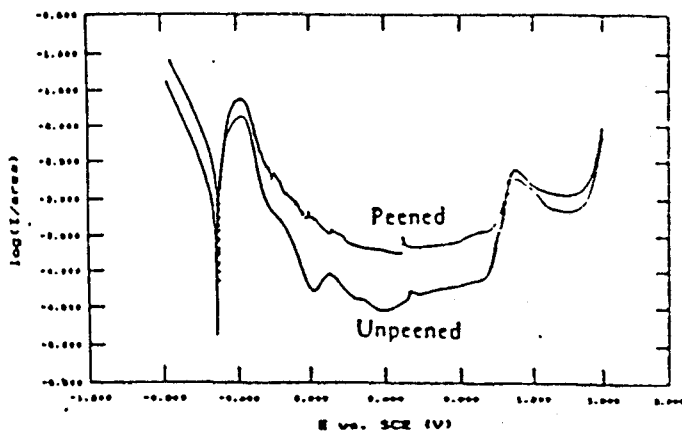


Fig.4 Potentiodynamic curve in 1 N H₂SO₄

From our observed anodic corrosion behavior diagrams we obtained the values of instantaneous corrosion current density, critical current density for passivation, the current density in the passive range, and the transpassive current density are tabulated in Table 1.

TABLE 1.

Sample	i_{corr} mA/Cm ²	Critical current density for passivation (mA/Cm ²)	Min.Current density in passive region (mA/Cm ²)	Transpassive current density (mA/Cm ²)
Unpeened	1.102	12.88	0.02191	1.93
Peened	2.98	23.5	0.177	2.55

b) The cyclic potentiodynamic scan in 1.0% and 3.5% NaCl medium

The observed free corrosion potential of the steel in 1.0% & 3.5% NaCl was -350 ± 20 and -320 ± 20 mV at 28°C. The cyclic polarization scan was initiated at -100mV cathodic to the observed E_{corr} and allowed to progress @ 1mV/Sec till a transpassive current rise was observed around 150mV anodic of E_{corr} , and at this juncture the scan was reversed till the starting potential was reached. The resulting cyclic polarization behaviour of virgin and peened samples in 1.0% and 3.5 % NaCl is depicted in Fig 5 & 6 respectively.

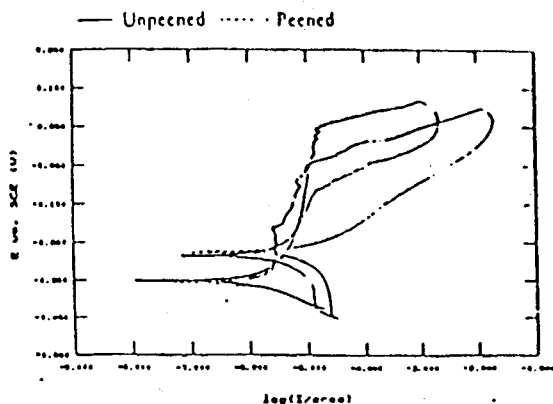


Fig.5 Cyclic Polarization curve in 1% NaCl

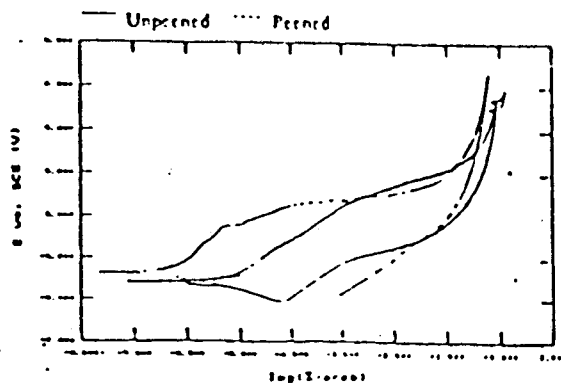


Fig.6 Cyclic Polarization curve in 3.5% NaCl

The extracted E_{corr} , i_{corr} , and the electro chemical charge under the reverse anodic loop are all given in Table 2.

TABLE 2.

Sample	Environment	E_{corr} (V)	i_{corr} $\mu\text{A}/\text{cm}^2$	Charge C/cm^2	E_b (V)	E_p (V)
Unpeened	1.0% NaCl	-0.3501	3.787	0.2576	0.041	-0.194
Peened	1.0% NaCl	-0.3554	1.019	2.298	-0.054	-0.268
Unpeened	3.5% NaCl	-0.319	1.411	13	Not well defined	-0.411
Peened	3.5% NaCl	-0.275	0.1581	6	-0.055	Not well defined

The visual and microscopic examination of the surface of the samples used in cyclic polarization revealed severe pitting in unpeened sample as compared to shot peened sample (Fig 7,8).

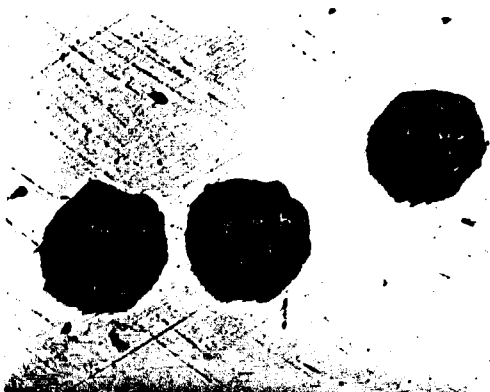


Fig. 7 Photograph showing pits on as polished sample subjected to cyclic polarization.



Fig. 8 Photograph showing pits on shot peened sample subjected to cyclic polarization

DISCUSSION

Considering the observed results of the polarization experiments we find that both the 12% chromium steel under unpeened and peened conditions, demonstrate well defined 'active', 'passive' and 'transpassive' potential regions, very typical of the corrosion behavior of steels in acid media. However, when we compare the unpeened and peened samples taken together, for their corrosion characterization, we find that their electrochemical behaviour is *similar* but *not superimposable*, with respect to current axis. In other words, the behaviour is superimposable with respect to potential axis. This exemplified by the fact that, the instantaneous corrosion current density for the unpeened steel is $i_{corr} = 1.102 \text{ mA}/\text{cm}^2$. The corresponding result for the peened specimen is $i_{corr} = 2.981 \text{ mA}/\text{cm}^2$. We thus find that, the peened sample experimentally demonstrates nearly 3.0 times higher instantaneous corrosion current density. Also, if we compare the currents in their passive region, we find that the lowest current density,

in the passive region is 0.022 mA/cm^2 for unpeened, while it is 0.18 mA/cm^2 for peened sample. Here again the peened surface demonstrates nearly 8 times higher current.

At the observed free corrosion potential (at which the instantaneous corrosion currents are recorded), of the specimen, it suffers corrosion due to the competing simultaneous reactions of the metal dissolution and hydrogen discharge. The involvement of hydrogen gas as a reaction product could mask the surface to some extent. On the other hand at the passive region no such gaseous reactions will be involved. Hence, the ratio of the passivation current density of the peened specimen to the unpeened specimen could be expected to reflect the enhanced surface area effect in the case of the former. In other words, electrochemical investigation reveals that the peened specimen will show higher current density compared to unpeened specimen and this excess current density could be attributed to the increased surface area of the shot peened sample, since the geometric area of both the samples under test was 1.0 sq.cm . This is further justifiable because the over all potentiodynamic behaviour of both the steels demonstrate similar corrosion behaviour, as far as potential regions (which implies that the corrosion reactions are same for both the steels in the chosen medium) are compared.

The observed higher current densities (which reflect the intensity of reactions) for the peened steel in the passive region is clearly indicative of the fact that the mechanical surface modification results in enhanced surface roughness that reflects in increased current in the anodic polarization behavior.

Now considering the cyclic polarization behavior of the steel in chloride media, we find that both the unpeened and peened specimens experimentally demonstrate hysteresis loops. Further, we observe that, in 1% chloride medium, both the steels develop well defined hysteresis, the nature of which is indicative of the their susceptibility to localized corrosion. In 3.5% chloride medium, the steels demonstrate more broader and open hysteresis, yet indicative of their susceptibility to localized corrosion.

When we examine the free corrosion potentials of unpeened and peened samples, we observe that peened sample is more noble to unpeened sample, within the duration of our experiments. When we estimate the electrochemical charge under the hysteresis we find that the charge is less for peened sample than compared with unpeened sample. This means that the peened surface suffers lesser degree of localized attack. This has further been confirmed by microscopic examination of the samples subjected to cyclic polarization.

CONCLUSIONS

① Studies on virgin and shot peened samples in air and in 3.5% NaCl showed an improvement of 25% and 40% in fatigue and corrosion fatigue resistance respectively by shot peening. SCC resistance was also found to improve substantially. This is mainly because it takes a very long time for a pit to grow through shot peened layer. Only when this layer is penetrated a crack can initiate leading to failure.

② The results obtained in acid medium clearly indicate that 12% Cr steel demonstrate well defined Active, Passive and Transpassive characterisation. The current densities for all potential regions are higher for peened sample as compared to unpeened sample. The excess current density could be attributed to the increased surface area of the shot peened samples. The higher current density in the passive region is clearly indicative of the fact that the mechanical surface modifications do affect the passivation character of the steel.

③ Considering cyclic polarization behavior of the steel in chloride media, we observe that the peened steel appears to be more noble compared to unpeened sample in 3.5% NaCl in contrast with its behaviour in 1% NaCl solution, Since the free corrosion potential is more noble ($E_{\text{corr}} = -275 \text{mv}$) compared to unpeened sample ($E_{\text{corr}} = -320 \text{mv}$) by about 45mv. This apparent nobility

of peened steel is maintained in its 10 times lower corrosion current density and also in reflecting lesser electro chemical charge in the pitting hysteresis loop.

④ Surface examination of the sample used in cyclic polarization confirm the above findings as severe pitting was observed in unpeened sample in 3.5% NaCl as compared to peened sample.

Based on the above facts, we conclude that the mechanical surface modification could have a strong bearing not only on the passivation behaviour of the steel, but also on the localized corrosion behaviour. Hence, we believe at this stage, that the electrochemically pre-passivated unpeened and peened samples deserve to be subjected to localized corrosion test and fatigue tests in order to have deeper understanding of aqueous corrosion fatigue phenomena.

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