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ROLE OF SHOT PEENING ON LIFE EXTENSION OF 12% Cr TURBINE BLADING MARTENSITIC STEEL SUBJECTED TO SCC AND CORROSION FATIGUE

G.V. PRABHUGAUNKAR*, M.S. RAWAT AND C.R. PRASAD

*IIT Mumbai, BHEL (R&D) Hyderabad, India.

ABSTRACT

Shot peening is known to enhance the fatigue strength of the materials. A systematic study of the role of shot peening on surface residual stresses and its effect on SCC and corrosion fatigue has been investigated in 3.5% NaCl solution. Controlled shot peening depth in relation to pit size is found to enhance resistance to SCC as well as corrosion fatigue. The role of surface stresses and mechanism controlling crack initiation and propagation are discussed.

KEY WORDS

Shot peening, Residual stress, Pit, SCC, Fatigue, Corrosion fatigue

INTRODUCTION

12% low carbon martensitic steel is used in various power plant components such as HP turbine control valve stem, boiler feed pump shafts, steam turbine blades etc. Among them, due to severe environmental conditions and loading pattern, steam turbine blades are considered to be quite critical from failure point of view. Number of blade failures have been reported world over. Failure statistics clearly indicate that most of the blade failures occur in the low pressure region of the turbine (1). Several failures reported from power stations operating in India were analyzed and found to be due to fatigue, corrosion fatigue and stress corrosion cracking. Some failures have also been encountered wherein improper heat treatment was the cause attributed to the failure. However such occurrences are very few and considerable work has been done on the effect of heat treatment on mechanical properties of 12% Cr steel (2).

Shot peening is a cold working process accomplished by bombarding the surface of the material with spherical steel balls impelled at high speed, thereby producing a layer of high magnitude of compressive residual stresses. It is very well known that shot peening improves the fatigue properties of a material (3 and 4) however not much work is done on its influence on corrosion properties of blading steel. In order to study the behaviour of shot peened steel in air and corrosive medium and to ascertain the role of residual stresses on the life of blading steel, the present work is undertaken which not only has research interest but also has direct practical application in power and allied industries.

MEASUREMENT OF PEENING DEPTH

In order to obtain optimum peening parameters, experiments were conducted by peening block samples with 50x18x6 mm dimensions employing various shot size and pressure combinations. Initially peening intensity was estimated using Almen Strips A and the data for 1.0mm dia shots with 4.0 kg/cm^2 pressure is presented in Fig 1. Thereafter block samples were peened keeping stand off distance of 140 mm and nozzle dia of 60 mm.

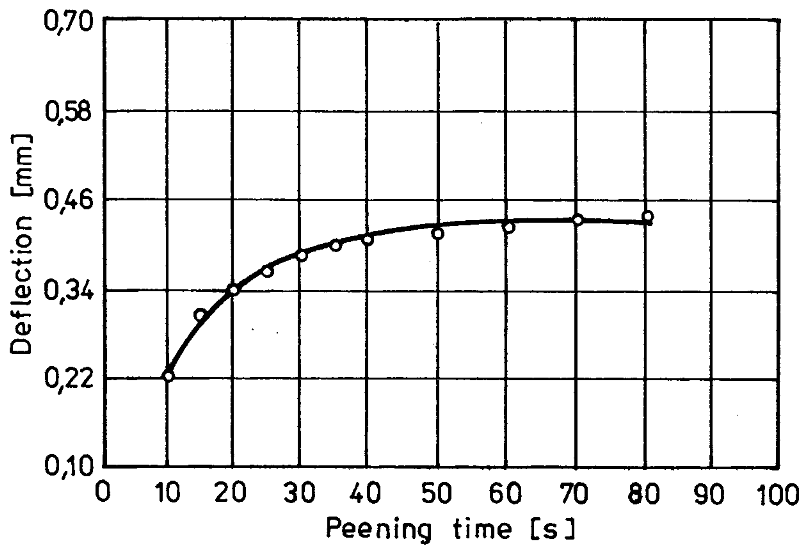

Fig.1 Saturation curve

Residual stresses were measured on the surface of the shot peened block samples after successfully removing layers of material by electropolishing. The original thickness of the sample was measured using digital micrometer. After each operation of electropolishing the change in sample thickness was measured which gives the amount of material removed. The experiments were conducted using different dia shots and varying pressure settings. It was observed that shot dia of 1.0mm with 4.0 kg/cm^2 gave optimum shot peening depth. The variation of residual stress with depth for 3.0 and 4.0 pressure conditions is given in Fig.2. Test samples were shot peened using these parameters for carrying out further experiments.

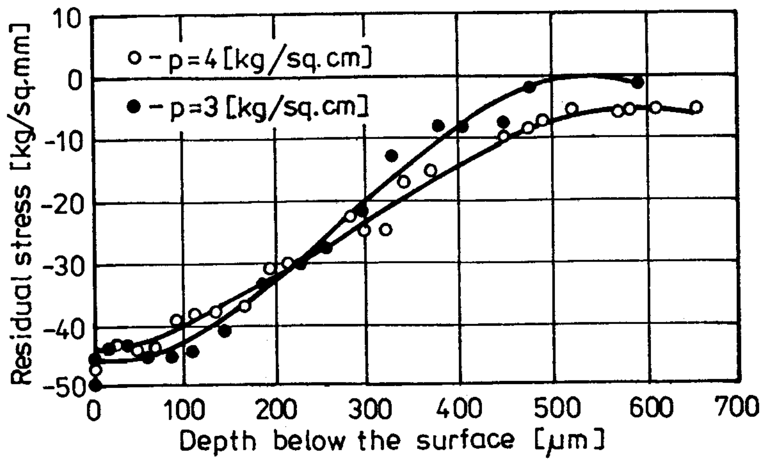

Fig.2 Variation of residual stress with depth

FATIGUE TESTING

High cycle fatigue and corrosion fatigue tests using round specimens were carried out on rotary bending fatigue testing machine of schenck PUNZ machines. The specimens required for the tests were made out of bar stock of 34x22 mm section. A coolant was used during machining to avoid heating of the specimen surface. Final polishing of the specimen was carried out in the longitudinal direction of the test bar. The data for unpeened and peened specimens is given in table 1.

Table 1. Fatigue testing in air

S.No.	Applied Stress Kg/mm^2	No. of cycles, $x10^3$ (unpeened)	No. of cycles, $x10^3$ (peened)
1	60	17	29
2	55	36	90
3	50	100	2100
4	45	570	1100
5	44	1000	18000 N_f
6	40	3800	22000 N_f
7	36	11000 N_f	21000 N_f

CORROSION FATIGUE TESTING

Most power plants in India employ sea water cooling for condensers and heat exchangers, and any leakage is going to be highly dangerous with respect to the life of the components. In order to simulate the most stringent conditions, 3.5% NaCl solution was chosen for conducting the experiments. Accordingly corrosion fatigue tests on 12% Cr blading steel samples were carried out in 3.5% NaCl environment. The solutions were prepared by mixing laboratory quality

NaCl in demineralized water. During testing, the solution was continuously sprayed on the specimen which was enclosed in a transparent Plexiglas housing. A nozzle having width corresponding to gauge length of the sample is fixed on the housing cover to obtain uniform wetting. Results obtain from the above test are presented in Table 2.

TABLE 2. Corrosion fatigue data on 12% Cr steel tested in 3.5% NaCl environment

Sl.No.	Stress Kg/mm^2	Cycles to failure	
		Unpeened	Peened
1	30	1.3×10^6	2.7×10^6
2	28	2.0×10^6	4.1×10^6
3	25	3.0×10^6	9.0×10^6
4	24	5.3×10^6	3.1×10^7 N_f
5	22	6.6×10^6	1.0×10^7 N_f
6	20	8.5×10^6	1.2×10^7 N_f
7	18	9.0×10^6	2.0×10^7 N_f
8	17	$3.1 \times 10^7 N_f$	3.1×10^7 N_f

- N_f = Not failed.

FRACTURE SURFACE EXAMINATION

The fracture surface of the failed sample was examined under scanning electron microscope (Fig 3) which showed multiple origin of cracks. Fig 3a shows a pit from where crack has initiated. Fig 3b shows a pit puncturing the surface through the edge of the sample. Fig 3c shows intercrystalline features near the crack initiation region followed by fatigue striation and Fig 3d is the final fracture region showing dimples. This shows that the initiation of a crack is through pits followed by intercrystalline features.

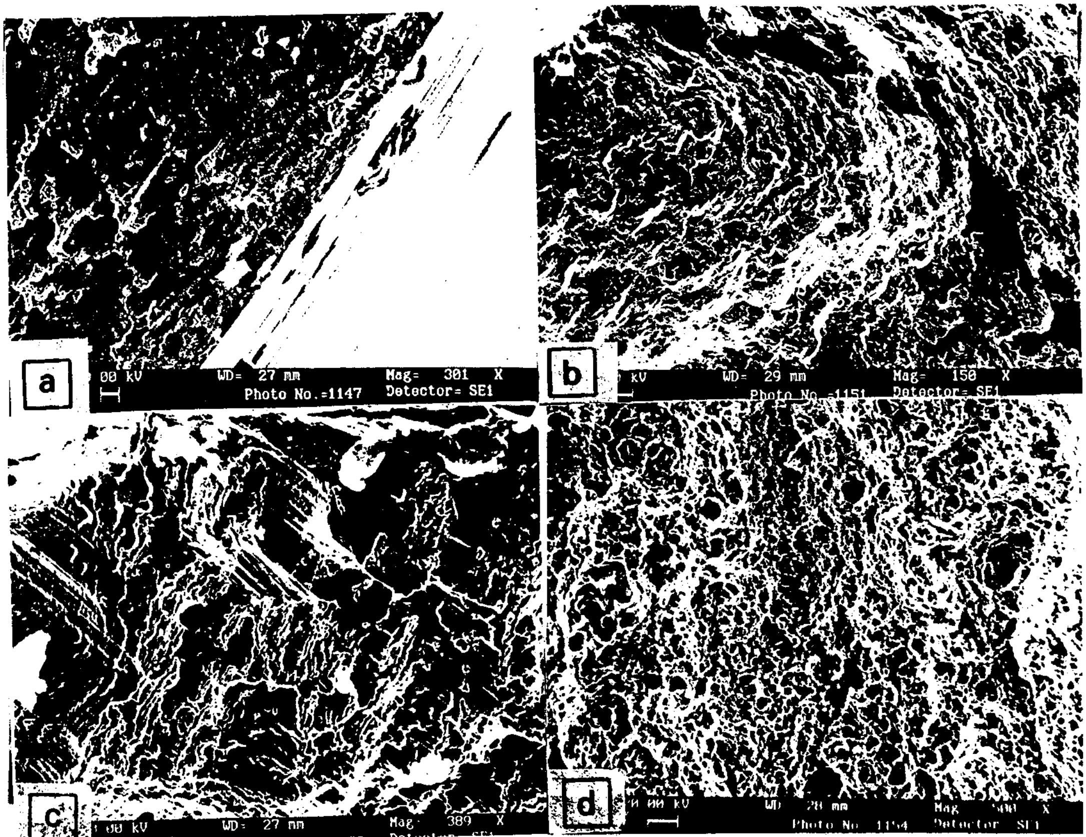

Fig.3 Fractographs showing (a) pits (b) puncturing of pit (c) intercrystalline features (d) final fracture region

STRESS CORROSION TESTING

U-bend specimen is bent 180 degrees around a pre determined radius and maintained in the resulting constant strain condition during the stress corrosion test. Since U-bend usually contains large amounts of elastic and plastic strain, it provides one of the most severe tests available for smooth stress corrosion test specimens. In the present case a strip of 100x9x3 mm was taken and stressing was achieved by single stage stressing. The stress of principal interest in the U-bend specimen is circumferential. It is non uniform because there is a stress gradient through the thickness varying from a maximum tension on the outer surface to a maximum compression on the inner surface. The stress varies from zero at the ends of the specimen to a maximum at the center of the bend and the stress may also very across the width of the bend.

The bolt used to maintain the stress is of plastic material to avoid galvanic corrosion effect. Peened and unpeened specimens in different tempering conditions were subjected to the test by immersing in 3.5% NaCl solution and the results are shown in Table 3.

TABLE 3. Stress corrosion cracking data

S.No.	Tempering Temperature in °C	Time to failure in 3.5% NaCl (in Hours)	
		Virgin material	Shot peened material
1	250	72	195
2	375	84	195
3	450	36	160
4	500	24	150
5	550	108	290
6	600	264	610
7	675	336	1040
8	675+550	280	680

DISCUSSION

The effect of shot peening on improving corrosion fatigue resistance of 12% Cr steel has generated a great deal of controversy. Speidel (1) and Schneider (5) have opined that, since corrosion fatigue cracks in 12% Cr steels originate from corrosion pits, the shot peened layer would be penetrated thus making it ineffective. Schneider also mentions that the size of corrosion pits are of the order of 0.1mm.

Not much work appears to have been carried out with varying shot diameters and other peening parameters to produce varying peening depths. However, published literature of EPRI (6) show that corrosion fatigue resistance of shot peened 12%Cr steel does improve in 22%Nacl solution. These results suggest that peening in a controlled manner with shots of sufficient diameter can produce favourably stressed layers of sufficient depth to improve the corrosion fatigue resistance, even of materials prone to pitting. Obviously when sufficient depth of peened layer is available, the time required to penetrate this depth will cause a delay in the formation of a fatigue crack. This is so because, as long as the pit is within the peened layer, the compressive stresses will not permit the fatigue crack to initiate.

Fatigue tests in air and corrosion fatigue tests in 3.5% NaCl show that the fatigue strength and corrosion fatigue resistance and stress corrosion resistance improves remarkably by shot peening.

The fracture surface examination of corrosion fatigue specimens showed that initiation of a crack is through pits followed by intercrystalline features (fig. 3), clearly suggesting that a stress corrosion crack starts underneath a pit which is then followed by corrosion fatigue. For corrosion fatigue to occur three parameters viz. Corrosive medium, material and alternating stress should interact. In material such as 12% Cr. Steel we have presence of a passive layer protecting the material. Next stage involves the nucleation of a corrosion pit. Metal vacancies may accumulate and form voids at the metal film interface. When voids grow to a critical size, the passive film collapses leading to the formation of a pit.

Thereafter the corrosion pit grows through the shot peened layer. This layer could be as deep as 0.5mm

(Fig 2) when 1.0 mm dia. shots are used. As in the pit nucleation stage, here the pit can grow only by anodic dissolution within the pit and the breakdown of the passive layer can take place only due to reasons other than those associated with fatigue. The deeper the shot peened layer the longer it will take for the pit to penetrate it. Once the shot peened layer is penetrated, stress corrosion crack will be initiated at the pit bottom followed by nucleation of a fatigue crack .This observation may be the reason for observing intergranular features at crack initiating regions(Fig. 3c).

This explains why speidel (1) did not find improvement in corrosion fatigue properties as he used lesser diameter glass bead shots which would have produced very shallow depth of compressive stress layer. He based his assumption on a pit 0.1mm deep penetrating the shot peened layer. It would be easier for a crack to start from a pit which is already deeper than the shot peened layer.

CONCLUSIONS

In 12% Cr steel, the optimum parameters for shot peening were found to have a pressure of 4.0 kg/mm^2 using 1.0mm dia shots.

Fatigue properties in air have been improved by about 25%. More pronounced effect is found in the improvement in corrosion fatigue resistance which in the present work has been found to be about 40%.

Stress corrosion cracking resistance for 12% Cr steel has been found higher for a tempering temperature of 675 ^{0}C which is further enhanced by shot peening to about three times.

Higher peening depth is beneficial for improving corrosion resistance.

Fractographic study revealed that pits are normally associated with corrosion fatigue tests. A stress corrosion crack starts underneath a pit followed by corrosion fatigue.

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