SELECTION OF OPTIMUM PEENING PARAMETERS TO IMPROVE THE STRESS CORROSION CRACKING RESISTANCE OF 18Mn 4Cr GENERATOR END RETAINING RING STEEL

N.Mukhopadhyay and C.R.Prasad
Corporate R&D Division
Bharat Heavy Electricals Limited,
Hyderabad - 500 593, **INDIA**
and
M.C.Sharma
Maulana Azad College of Technology,
Bhopal - 462 007, **INDIA**

ABSTRACT

The effect of peening parameters such as shot size, nozzle pressure and peening time on 18Mn4Cr austenitic steel has been studied. Peening led to the formation of compressive residual stress layer on the surface, martensite transformation in some cases and reduced the surface roughness. Based on the results, a set of optimum peening parameters was evolved. Unpeened and peened specimens were tested for their susceptibility to stress corrosion in oxygenated aqueous chloride medium at 70°C using a 3-point bend test method. The results indicate a considerable improvement in crack initiation time in peened specimens, compared to unpeened specimens.

INTRODUCTION

Turbogenerator rotor end retaining rings remain highly stressed both when the machine is operating and when it is under shutdown. Often these rings have undergone failures by stress corrosion owing to unfavourable environmental conditions [1,2]. The rings are recommended for use in dry environment [3]. But wet conditions often encountered in operation due to leakage of stator cooling water and during shutdown lead to cracking. Cracking which occurs in pure water is known to be aggravated in presence of chloride and nitrate [2]. However, oxygen has been found to be an essential factor in cracking of nonmagnetic end retaining rings by stress corrosion [4].

Besides maintaining a dry environment to prevent cracking of end rings as suggested by Speidel [3], other preventive measures have been tried elsewhere. One of these measures can be shot peening which was carried out on rings made from 8Mn8Ni4Cr austenitic steel [5]. 18Mn4Cr steel is another end ring steel which is used widely and finds preference over 8Mn8Ni4Cr steel owing to the former's smaller Y.S./U.T.S. ratio in a comparable yield strength range. For example, while 18Mn4Cr rings have such a ratio in the range of 0.76-0.80 in the yield strength range of 921-990 MPa, 8Mn8Ni4Cr rings have a ratio of 0.87-0.93 in the yield strength range of 784-912 MPa.

In the present study an attempt was made to establish an optimum set of peening parameters through laboratory investigations. These peening parameters were then used to study the effect of shot peening on the stress corrosion cracking resistance of 18Mn4Cr steel.

EXPERIMENTALS

A virgin retaining ring was used for the investigation. The chemical composition and mechanical properties of this ring are presented in Table 1.

Shot peening was carried out with hardened steel shots of different sizes. These shot sizes are designated as OSS-3(1.40mm) OSS-5(1.00mm), OSS-6(0.825mm), OSS-7(0.700mm) and OSS-8(0.575mm) depending upon their average diameters. The peening pressures used were 0.588MPa and 0.784 MPa. The peening nozzle diameter was 6 mm and the stand-off distance was 45 mm. Type A Almen strips were used for measurement of peening intensity. Peening times varied between 1 and 8 mins. The assessment of peening effect on the physical properties of the material was carried out on block specimens of 40 mm x 20 mm x 10 mm size. These specimens were metallographically polished on one side (40 mm x 20 mm area) for peening with steel shots and subsequently for determination of residual stress, phase transformation and surface roughness. The details of the peening instrument used is given in reference 6.

Residual stress measurement on the peened surface as well as at different depths of peened layer was performed by using Rigaku microprocessor based $Sin^2\psi$ diffractometer in which the slope of $Sin^2\psi$ vs 2θ axis can be directly read. The slope is then converted into the residual stress value by using a calibrated material x-ray elastic constant. The measurement of residual stress at different depths was performed after successively

removing layers of materials from the surface by electropolishing.

In order to find out the effect of peening on stress corrosion cracking a test apparatus based on 3-point bend test method was designed and fabricated using the following relationship :

$$\sigma = \frac{6Ety}{H^2}$$

where σ = maximum tensile stress
E = modulus of elasticity
t = thickness of flat specimen
y = maximum deflection
H = distance between outer supports

Flat specimens of 140 mm x 15 mm x 3 mm (l x b x t) size were used to satisfy the small deflection condition(y/H $<$ 0.1) on which the above relationship is based. The specimens were fabricated by spark erosion machining to minimise introduction of residual stress. Specimens under load were exposed to vapours of boiling 3% NaCl solution such that the temperature of the condensed vapours on the specimen surface remained between 65°C and 70°C. It was observed that supply of oxygen was necessary to promote cracking. After each interval of exposure, the specimen was examined for presence of a crack using liquid dye penetrant test.

RESULTS AND DISCUSSION

Residual Stress

Figure 1 shows the variation of compressive residual stresses developed in the peened specimens at various depths from the peened surface. Each curve in the figure was plotted after peening a specimen with a particular shot size for 3 minutes. It is evident from the figure that even though the surface residual compressive stresses vary marginally with shot sizes, the 1 mm shots have a greater effect on the material in terms of a higher value of stress at any particular depth. It is also seen that a favourable compressive residual stress could be produced upto a depth of at least 0.6-0.8 mm using the 1 mm shots. Further, the amount of compressive residual stress produced on the surface is 52% of U.T.S. of the ring.

Formation of Martensite

Martensite formed due to peening of austenitic steel will lead to generation of local stress due to a volume change associated with the transformation. Therefore, one of the conditions of optimum peening is to restrict the formation of martensite. Table 2 shows how the amount of transformed martensite increases in this steel due to peening with increased shot sizes. Peening with 1.4mm and 1.0 mm shot sizes promotes martensite formation. Martensite was identified from the positions of (311)γ , (211)α and (220)γ peaks using Mo K_α radiation. It is evident from the table that while steel shots of 1.40 mm size is likely to produce martensite even for minimum peening time, using 1.0 mm steel shots at a nozzle air pressure of 0.588 MPa will produce minimum amount of martensite in a peening time of 3 minutes. This peening time was

also found to produce sufficient coverage and depth of compressive residual stress.

Surface Roughness

It is desired that a machined retaining ring should retain a surface finish of the order of 1.6 μm C.L.A. To examine the effect of shot peening using 1 mm shots on the surface finish, peening was carried out on a surface with 1.6 μm C.L.A. finish. It was found that the above peening has, in fact, improved the surface finish to 1.2 μm C.L.A. (Table 3).
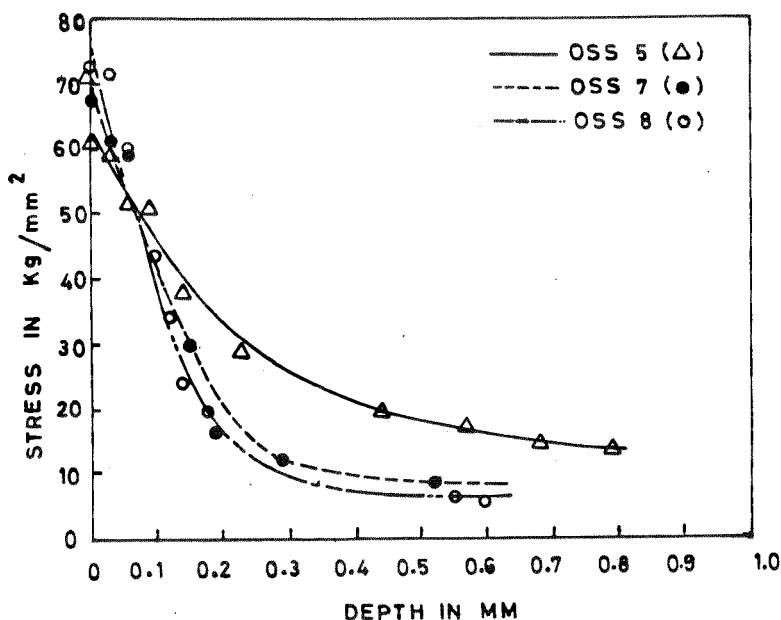

Figure 1   Compressive Residual Stress at Various Depths in Specimens Peened with Shots of Different Sizes.

Stress Corrosion

From the results of residual stress measurement, martensitic transformation and surface roughness, it has been possible to evolve a set of optimum peening parameters: 1mm shot size, nozzle diameter of 6 mm, nozzle air pressure of 0.588 MPa, 45 mm stand-off and a peening time between 2 and 3 minutes. This set of parameters was used to peen stress corrosion test specimens for further investigation. The results of stress corrosion are shown in Table 4. During the tests unpeened specimens revealed crack formation within 200 hours of exposure. The specimen fixture along with a typical stress corrosion crack in an unpeened specimen are shown in figure 2. But the peened specimens withstood stress corrosion for as long as 1040 hours. Therefore, using the

optimum parameters, at least a five-fold increase in stress corrosion life has been achieved.
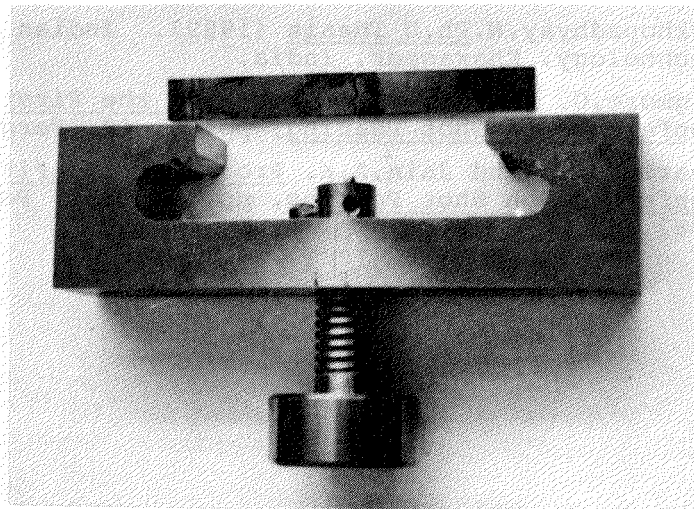

Figure 2   Unpeened Specimen Cracked after Stress Corrosion Test and the Fixture Used for the Test

CONCLUSIONS

1. X-ray diffraction studies have shown that favourable compressive residual stresses upto a depth of 0.6 mm to 0.8 mm can be achieved by using the established set of peening parameters without the formation of martensite.

2. Peening with these parameters has also resulted in improving the surface finish.

3. Stress corrosion cracking resistance of the material has been improved five-fold using the above set of peening parameters.

ACKNOWLEDGEMENTS

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TABLE 1   Chemical Composition and Mechanical Properties of the Retaining Ring under Investigation

C	S	P	Mn	Cr	Al	V	Ni	Si
0.52	0.01	0.02	18.98	3.87	0.035	0.05	0.15	1.04

0.2% Y.S. MPa	U.T.S. MPa	% Elongation (G.L.=25 mm)	% Reduction in area	Hardness HB
923.7	1141.9	27.7	41.0	352

Chemical analysis in wt %

TABLE 2   Effect of Peening Condition on Formation of Martensite

Peening Condition			Amount of martensite %
Shot size	Air pressure MPa	Peening time min.	
OSS-3	0.588	4	5.0
OSS-5	0.588	6	1.5
OSS-5	0.588	8	3.5
OSS-5	0.784	6	10.0
OSS-5	0.784	8	7.3
Unpeened	-	-	Nil

TABLE 3   Effect of Peening on Surface Finish

Starting surface	Type of shots	Nozzle pressure MPa	Peening time min.	Surface finish μm, C.L.A.
Unpeened	-	-	-	1.6
Peened	OSS-5	0.588	2	1.2

TABLE 4 **Effect of Peening on Stress Corrosion Crack Initiation**

Sl. No.	Specimen condition	Load 0.2% Y.S	Time-to-failure hours
1	Unpeened	60	200
2	Unpeened	60	149
3	Peened	60	519 (N.F.)
4	Peened	60	700 (N.F.)
5	Peened	60	1040 (N.F.)

Environment	:	Vapours of boiling 3% NaCl solution, temperature 65°C - 70°C, O_2 environment at 1.3 lit. per min.
Peening condition	:	Steel shots 1 mm dia, nozzle air pressure 0.588 MPa, peening time 2 mins.
N.F.	:	Not failed