THE USE OF SHOT PEENING TO DELAY STRESS CORROSION CRACK INITIATION IN AUSTENITIC 8Mn8Ni4Cr GENERATOR END RING STEEL

G. Wigmore and L. Miles

Central Electricity Generating Board, South West Region, Bristol, UK

ABSTRACT

Shot peening is shown to delay stress corrosion crack initiation in austenitic 8Mn8Ni4Cr generator end ring steel in aqueous environments. However for maximum protection an optimum peening intensity exists; beyond this the decrease in resistance to cracking is shown to result from the formation of deformation induced martensite.

Similar effects are expected from shot peening of other austenitic steels which can transform to martensite by deformation, and thus in an environment likely to lead to stress corrosion the choice of peening parameters can be critical.

KEYWORDS

Shot peening; high manganese austenitic steels; generator end rings; martensite by deformation; optimum peening intensity.

INTRODUCTION

End rings are used on large AC electrical generator rotors to retain copper windings where they exit from axial slots and bend round to form pole faces. To limit eddy current losses a non-magnetic material of high strength is required to withstand high centrifugal stresses. A typical ring would have dimensions of 1m internal diameter, 600 mm length and 50 mm wall thickness.

Failures of end rings have occurred world wide, Gibb (1955); Lissner (1957); CEGB (1973); Parsons (1974), and the majority of these have been attributed to stress corrosion cracking which probably occurred due to condensation onto the rings during an out-of-service period or due to water leakage from a water cooled rotor during operation, Kellenberger and Krick (1974). In a conventional air or hydrogen cooled generator condensation is unlikely during service and thus a base-load machine should be at little risk. The risk of stress corrosion cracking does however increase as generators experience two-shifting or when long periods without operation occur. The problem of assessing the integrity of austenitic end rings using fracture mechanics is difficult since the stress corrosion crack growth rates can be high and uncertainties exist about the level and distribution of residual stress in end rings. Within the CEGB we take the view that returning a cracked end ring to service represents an unquantifiable risk, and thus efforts are concentrated on reducing the likelihood of stress corrosion crack initiation. For older rings made from 8Mn8Ni4Cr austenitic steel in the South West Region we have employed shot peening to retard crack initiation, and in some cases this has been combined with efforts to minimise the chances of moisture condensing on rings by fitting dehumidifying driers.

This paper describes laboratory work which has been carried out to examine the effect of shot peening in 8Mn8Ni4Cr, and the control of the process which is required to give optimum resistance to stress corrosion crack initiation.

THE EFFECT OF SHOT PEENING ON INITIATION

The analysis and mechanical properties of the 8Mn8Ni4Cr austenitic steel are given in Table 1. The material had been cut from an end ring which cracked in service at Plymouth Power Station, although cracking was detected by routine examination before any ring failure could occur.

TABLE 1 CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES OF 8Mn8Ni4Cr END RING

Carbon	0.6
Silicon	0.3
Manganese	6.8
Chromium	4.1
Vanadium	<0.1
Nickel	7.9
Sulphur	0.01
Phosphorus	.05
Molybdenum	<0.1
Titanium	<0.1

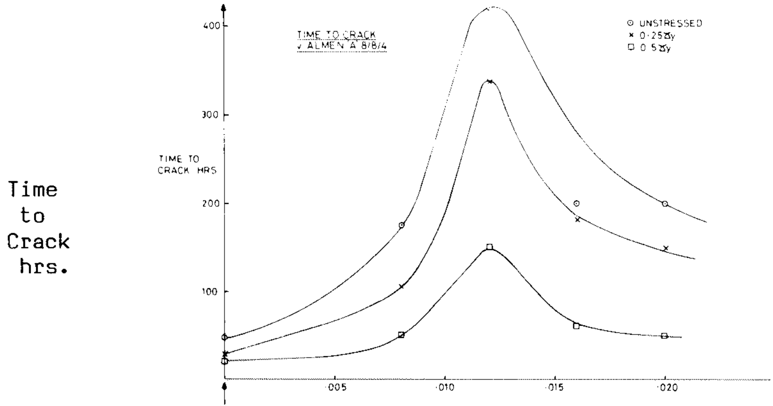
Yield Point	800 $MN.m^{-2}$,52 tsi
Ultimate Tensile Strength	1129 $MN.m^{-2}$,73 tsi

Samples 65 mm x 12 mm x 3 mm were given controlled shot peening treatments as follows:

Shot	230 H	(round iron)
Coverage	200 %	
Intensity	.008, .012, .016, .020 Almen A	

Peened and unpeened specimens were tested in three point bending by suspending them over boiling 1% sodium chloride solution. The chloride solution was chosen since metallographic examination of cracked rings after service had shown similar features to those samples cracked in chloride in the laboratory. A number of unpeened samples were also tested for comparison.

Specimens were tested at an outer fibre stress corresponding to 0.25σ yield and 0.5σ yield as well as unstressed. The fact that specimens without externally applied stress cracked, was the first indication that residual tensile stresses existed at the surface of machined specimens and this aspect was followed up subsequently using an X-ray technique.

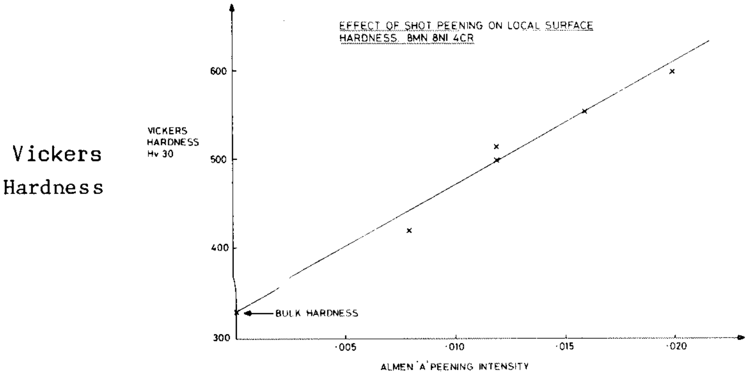


Peening Intensity
Fig.1

Figure 1 shows the stress corrosion crack initiation results for the three stress cases after shot peening and compares them with results on unpeened samples. It is clear that peening can increase resistance to crack initiation, but is most effective for samples with low levels of applied stress. It is very effective for nominally unstressed samples which contain only surface residual machining stresses. This is precisely the state which much of a real end ring experiences when the generator is off-load and moisture might be condensing on metal surfaces. (The shrink region is the only area under applied stress in this condition). One other important feature of Fig. 1 is that resistance to cracking goes through a maximum, peaking sharply at a value around .012 Almen peening intensity. This is the Almen intensity that we have specified for generator end rings in South West Region CEGB.

THE EFFECT OF PEENING ON MECHANICAL PROPERTIES

8Mn8Ni4Cr is a very work hardenable steel and a local increase in surface hardness results from machining processes. A similar local increase in hardness at the surface results from shot peening with higher Almen intensities leading to greater hardness levels (Fig. 2).

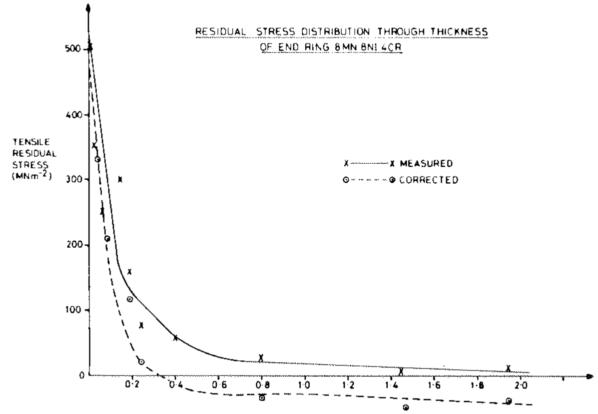


Almen A Peening Intensity
Fig.2

EFFECT OF SHOT PEENING ON SURFACE RESIDUAL STRESS

The initiation in nominally unstressed, unpeened samples indicated the presence of residual tensile stresses at the surface as a result of machining. An X-ray technique was used to determine the level of residual stresses at the free surface and after removing layers by chemical polishing.

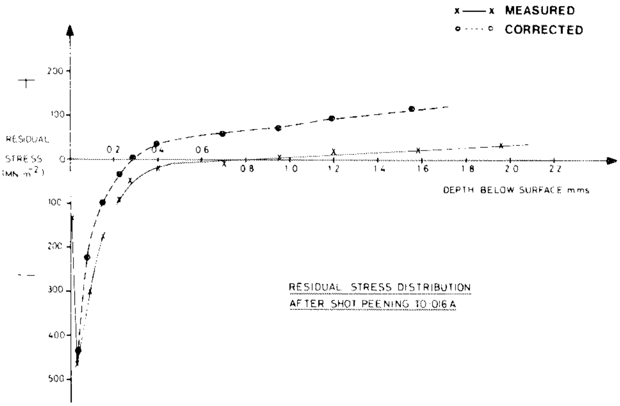
Tensile
Residual
Stress
($MN.m^{-2}$)



Depth Below Surface (mms).
Fig.3

Figure 3 shows the results for a generator end ring, peak surface stress levels around 500 $MN.m^{-2}$ (tensile) were observed but these decayed rapidly below the surface. Similar profiles have been produced for as-machinined samples, the peak tensile stress was again 500 $MN.m^{-2}$ but the stress decayed more rapidly.

Residual
Stress
($Mn.m^{-2}$)



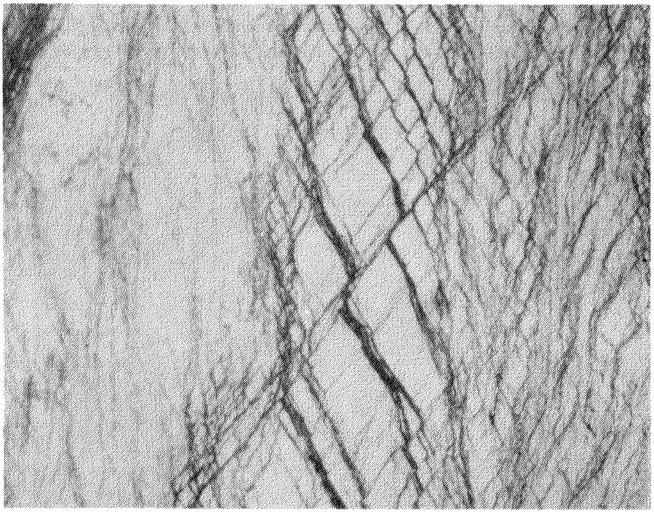
Depth Below Surface (mms).
Fig.4

The effect of shot peening on residual stresses is seen by comparing Fig.3 with Fig.4 which is for a sample peened to .016 Almen intensity. In this case a large surface compressive stress now exists at the surface although it is very shallow.

MICROSTRUCTURAL CHANGES ASSOCIATED WITH SHOT PEENING

Of major interest in the present work was the reason for the maximum in the initiation time/peening intensity curve. One strong possibility was that some phase change such as martensite formation was responsible and this was investigated with an X-ray diffraction technique.

Since the shot peened layer on a metal sample resulted in a surface region which varied rapidly with depth, both in hardness and residual stress, it was decided to reproduce similar metallurgical structures by uniformly cold rolling a sample of 8Mn8Ni4Cr end ring steel to a number of levels of reduction. The bulk hardness of the material (Hv350) increased rapidly with cold reduction up to a value of Hv600 at 75% reduction. Thus, from Fig. 2, it can be seen that peening to .020 Almen intensity results in a similar peak surface hardness to a cold reduction of 75%.



(800x)

Fig.5 Microstructure after 85% Cold Work

Figure 5 shows the microstructure after 85% cold reduction and etching in modified Fry's reagent. The presence of lath martensite is clearly indicated. Specimens with less cold work showed less martensite formation; those with less than 30% cold work, including the as received sample from the end ring, contained no martensite detectable by metallographic techniques.

Using the X-ray technique it was observed that cold work transformed the original austenite structure of the material into two types of martensite, ϵ and α.

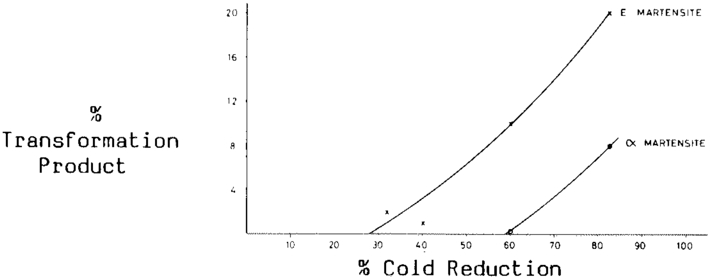


Fig.6

Figure 6 shows the formation of martensite as a function of uniform cold work in the sample. Below 30% cold work very little martensite exists but above this level ϵ starts to form. By 60% cold work α martensite is starting to form. α can be detected metallographically but ϵ is not detectable in this way as far as is known.

Considering now that the peak in the initiation time/peening intensity curve of Fig.1 occurs at .012 Almen which, from Fig.2, results in a peak surface hardness of Hv500, .012 Almen is equivalent to the hardening from a cold reduction of 45%. From Fig.6 this is seen to coincide with about 5% ϵ martensite only (no α martensite is present at this stage). Thus the conclusion is that shot peening is very beneficial in preventing stress corrosion crack initiation in 8Mn8Ni4Cr steel provided that the intensity is chosen such that martensite formation does not occur.

The very susceptible nature of martensite in the austenite structure to stress corrosion cracking was demonstrated by testing, without applied stress, a specimen cold reduced by 85%. After 100 hours in steam above a boiling NaCl solution extensive bands of cracks developed at the boundaries of martensite laths Fig.7.

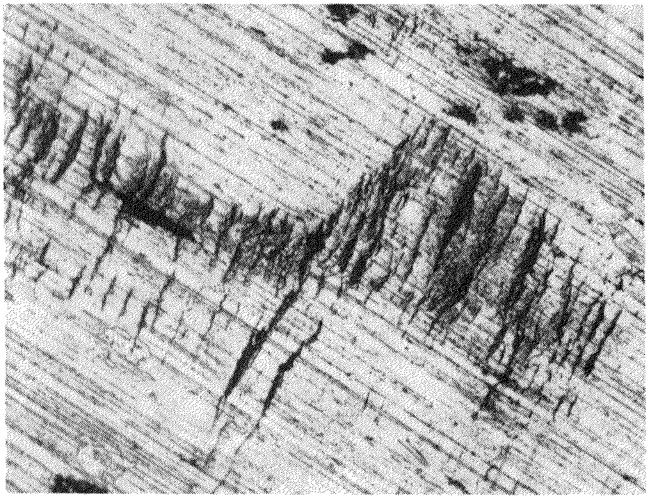

(350x)

Fig.7 Stress Corrosion Cracking Associated with Martensite.

VOLUME CHANGES RESULTING FROM MARTENSITE FORMATION

Electron diffraction of samples containing martensite showed the following orientation relationship:

$$(111)_\gamma // (0001)_\epsilon // (110)_\alpha$$

Shimizu and Tanaka have determined the same relationship for a 12% Mn alloy. X-ray measurements showed that a volume decrease was associated with austenite dissociation leading to strains of:

γ to ϵ , - 0.82% strain
γ to α , - 1.69% strain.

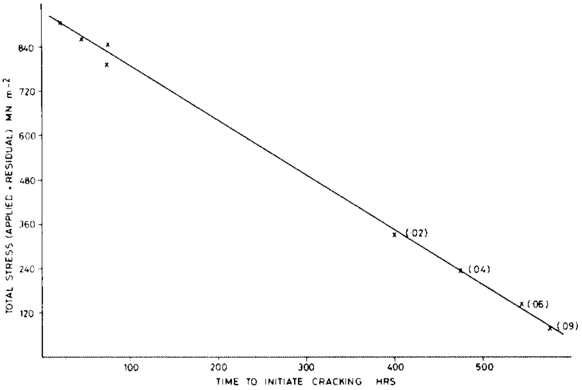
The volume change associated with martensite formation is likely to result in high local stresses at the interface between α and ϵ laths and the austenite matrix, and these are thought to be the cause of enhanced susceptibility to stress corrosion in samples containing martensite.

DISCUSSION

The Benefits Arising from Shot Peening 8Mn8Ni4Cr Steel

Residual surface stresses in an end ring are likely to be tensile and variable in magnitude from point to point. The evidence for this comes from X-ray residual stress measurements and from the observation that as-machined surfaces will stress corrode without external applied stress. Figure 8 demonstrates the importance of residual machining stresses in causing cracking.

Total
Stress
(Residual
+ Applied)
(MN.m^{-2})



Time to Initiate Cracking (HRS)
Fig.8

From the known residual stress/depth profile on a machined surface we have summed residual and applied stresses and observed the time to initiate stress corrosion cracking. The numbers in parentheses refer to the depth of surface layer removed by chemical polishing. 8Mn8Ni4Cr is clearly very susceptible to stress corrosion, and since we cannot use fracture mechanics to define a safe operation period for a ring containing a crack, we need to ensure that crack free rings enter service and crack initiation is delayed for as long as possible.

In the past rings have been painted for protection but the shrink fit areas cannot be painted because electrical contact between end rings and the rotor is essential. Thus shot peening is very attractive because it can be used all over rings in addition to the normal painted areas to confer increased stress corrosion resistance. It is likely to produce a uniform compressive stress on the surface to replace a variable tensile stress from machining (Birley and Alder 1980). Figure 1 ahows that maximum protection is conferred when the machine is at rest, then the majority of the ring surface is under residual stress and condensation of moisture is possible.

However it is essential to control the shot peening to the optimum peening intensity which just prevents the formation of martensite by deformation.

Martensite Formation by deformation in Austenitic Manganese Steels

Schumann (1970) has examined in detail the structure and mechanical properties of a range of Fe-Mn binary alloys. He showed that for less than 10% Mn austenite transforms to a b.c.t. form of martensite (α). Between 10 and 25% Mn a mixed martensite of α and ϵ (hexagonal) is formed, whilst for binary alloys between 15 and 28% Mn, the structure is completely ϵ. Above 28% Mn a completely austenitic structure results.

For commercial high manganese alloys the structure will depend on the precise composition; carbon is reported to stabilise austenite (Georgieva and others 1976), as most probably does nickel. Chromium is reported to reduce stacking fault energy and increase strain hardening rate (Drobnjak and Gordon Parr 1970). In the 8Mn8Ni4Cr alloy the as-received structure in a warm worked end ring is fully austenitic with an extensive grain boundary carbide network. Deformation at ambient temperatures, either from peening to a high Almen intensity, from cold reduction or from fast fracturing results in martensite formation. The X-ray measurements show that for the reaction $\gamma \rightarrow \epsilon + \alpha$ each transformation occurs with a contraction in volume, and thus high local tensile stresses will occur at the junctions between the martensite laths and residual austenite. Gordon-Parr (1952) and Holden, Bolton and Petty (1971) found similar contractions for the transformation in austenitic alloys. For an austenitic FeNiAl alloy Hornbogen (1978) showed that martensite formation local to a growing fatigue crack resulted in a volume increase and a retardation in growth rate due to internal compressive stresses.

A more recent austenitic end ring material which has replaced 8Mn8Ni4Cr is 18Mn4Cr. Preliminary tests indicate that this contains a considerable proportion of martensite in the as-received condition. Thus we have chosen not to shot peen such rings since it would induce further martensite formation and most probably increase susceptibility to stress corrosion. Povich (1977) using 304 stainless steel and Hay (1978) with 316 stainless steel have both shown that martensite formation was detrimental in aqueous conditions. Edeleanu (1953) has also shown that the susceptibility to stress corrosion cracking for a range of austenitic stainless steels depends on the ease of martensite formation after straining. He considered that the martensite so formed corroded preferentially.

For low carbon ferritic steels no phase change occurs on peening and Brown and Wilkins (1977) have shown that increases in resistance to stress corrosion can be achieved.

CONCLUSIONS

Shot peening of austenitic stainless steels can be of benefit for delaying the initiation of stress corrosion cracking in such materials provided that the process control is such that martensite formation does not occur during the peening.

Whether or not martensite forms depends on the M_s temperature of the steel compared with the peening temperature. This will be critically dependent on the precise chemical composition of the steel.

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