Effect of Shot Peening on Hardened High Carbon Steels and Its Mechanism

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ABSTRACT

Shot peening intensity is carefully selected so as to keep the hardness unchanged in hardened high carbon steel. Tested results show that the residual stress influence the growth of cracks less than 0.05mm, which is still in the crack initiation stage from engineering point of view. For ground smooth specimens, cracks initiate at the tip of the grinding scratchs, so surface topography plays an important role to the fatigue behavior.Microstress is the third but not the least factor that should be taken into account. With a constant hardness, the effects of residual stress, surface topography and microstress relief on fatigue limit are summarized quantitatively.

KEYWORDS

Residual stress, crack initiation, surface topography, microstress relief, fatigue strength, shot peening.

INTRODUCTION

Structure, residual stress and surface topography are factors in improving fatigue strength after shot peening. Some papers indicated that the microstructural effect could be characterized by raise of hardness, it increases resistance against deformation and crack initiation. This is noticeable especially in smooth specimen. On the other hand, compressive residual stress would decrease the crack propagation rate. Bahre(1978) found that the fatigue strength appeares to be in a linear relation to the hardness in both smooth and notched samples without residual stress. Müller(1981) suggested a model describing the effect of hardness on scattering slip distributions. It is known that the different stage of crack initiation and propagation can only be differentiated by detection technique. Generally, 0.1mm is taken as a limit for initiation from engineering point of view. 0.1mm is a presumptive threshold, while crack initiation and propagation are mechanical processes. It is inadequate to make a clear cut division between different mechanisms with an arbitrary value.

It may be reasonable to express the structure change in terms of hardness for annealed material. But for hardened steels, shot peening usually increases the hardness while the half width of X-ray profile decreases. For shot peening, decrease of half width is mainly due to microstress relief. Crack initiation and propagation are highly selective and preferential in weak region. Microstress relief would reduce weak regions, thus the fatigue strength is improved. Stress relaxation is unlikely correlated with hardness, therefore it won't be appropriate to express the structure change by hardness only.

Investigations have been reported on several papers,yet quite different were their conclusions. Balter(1978) achieved high compressive residual stress of 2500MPa in low temperature tempered 65Si2W steel, but the increment of the fatigue limit was only about 2%. Horwath(1981) claimed the minimum peening parameter would be the best for SAE1074 in HRc45-50, so it is better to create a shallow layer with high compressive stress. Koibuchi(1981) suggested that the residual stress acts as a mean stress and it is a predominant factor in high strength steel. The present paper attempts to clarify the above divergence.

EXPERIMENTAL PROCEDURES

Smooth round specimens in ϕ12x100mm were cut from GCr15 (AISA 52100) bar. They were 860°C quenched and tempered at 190°C for 2 hours and then ground.

Shot peening were brought about in pneumatic machine with chilled iron shots of ϕ0.6mm. The intensity was controlled in Almen 0.28A(mm) to keep the hardness (HRc60-61) basically unchanged.

Polishing in longitudinal direction was carried out with emery paper.

Pulsating fatigue was performed in three point bending. The mean stress was 1450MPa. The fatigue limit in terms of maximum alternating stress was determined when 60% samples endure 5×10^6 cycles.

In order to observe the crack initiation and propagation, one group of specimen were run at 112% of fatigue limit level and stopped at different cycle then broken under static load.

Residual stress distributions were measured by x-ray diffraction with Cr-Kα and (211) peak. The half width of the profile was recorded at ψ_0=0. Retained austenite was determined by x-ray. yet no appreciable change has been found. Fracture morphologies were investigated on SEM.

EXPERIMENTAL RESULTS AND DISCUSSIONS

X-ray results are shown in fig 1 and table 1. Fatigue limits are also included in table 1 .

Table 1 Data of x-ray measurement and fatigue limit

sample	fatigue limit (MPa)	residual stress (MPa)		half width (degree)#
		surface	average#	
Ground	360	-490	-40	6.8
Polished	525	-245	-10	6.2
Shot peened	650	-880	-880	5.3
Shot peened then polished	690	-980	-800	5.9

#Average value in the low crack growth rate region.

Close attention has been paid on the feature and the depth of different fracture regions near the fatigue origin. Some photos are shown in Fig.2.

1. Observation on the fracture surface shows several regions from the fatigue origin to the center:

a. Transgranular slip decoherence. (T)

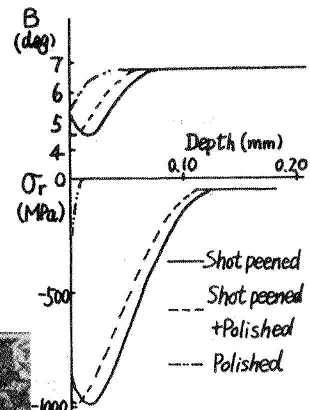

Fig.1 Residual stress and half width distribution

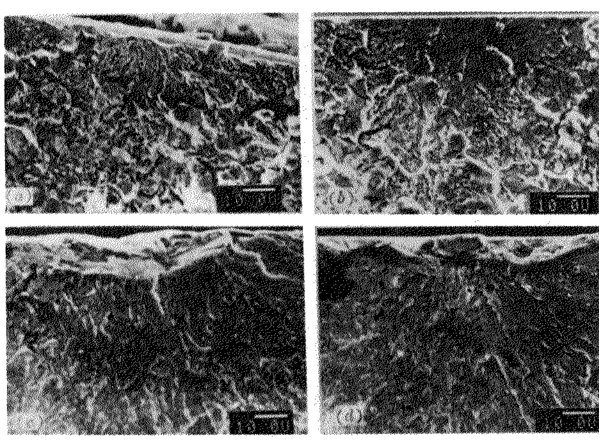

Fig.2 Fracture surface morphology
a. Ground b. Polished c. Shot peened
d. Shot peened then polished

b. Striation and intergranular fracture. (S+I)
c. Intergranular fracture and dimple. (I+D)
d. Dimple and quasi-cleavage. (D+C)

Table 2 shows the depth of each region and the location in which crack initiates. In specimens under a load of 112% fatigue limit only transgranular fracture of depth 45μm has been found. So that, T can be characterized as low crack growth rate region.

Table 2 characteristics of fracture surface

Sample	Crack initiation location	T depth(μm)	S+I depth(μm)	S+I % of I
Ground	scratch	20	40	much
Polished	inclusion	20	40	much
Shot peened	dent	40-50	80	little
Shot peened then polished	dent	40-50	80	little

The depths of transgranular crack observed in this experiment are no more than 50μm, From engineering point of view, 50μm is still in the crack initiation stage. Striation and intergranular cracks start from 50μm. Increase of T region depth can be explained by residual compressive stress, which lowers stress intensity factor at the crack tip.

2. In high carbon steel, martensite in plate form creates high microstress at its tip. The half width may reach 6-7 degrees. For short crack length and low ΔK value the plastic zone size ahead of a crack is small. If it is smaller than a grain, crack runs across the grain. When crack grows, ΔK increases, the plastic zone will cover several grains, thus, original austenite grain boundary can be selected as a propagation path indicating intergranular crack. A paper on quenched 20Cr13 steel shows the similar results. The effect of microstress is significiant especially in low crack growth rate region. (Romaniv,1982) Drastic deformation in shot peening reduces local stress peak and its inhomogeneous distribution as well. Consequently, in S+I region the portion of intergranular crack decreases (table 2).

3. High carbon steel is sensitive to notch effect. Its fatigue strength is greatly affected by surface topography. The depth of grinding scratch is about 5μm. This surface detriment brings out crack and then it grows inwards. Therefore, even in a ground smooth specimen, the crack is unlikely initiated at the slip band after plastic deformation. Shot peening leaves tiny dents on the surface as fig.2 c,d, crack initiates at the bottom of these dents. Since the sharpness of a dent is far less than that of a grinding scratch, surface quality is somehow improved. When a peened specimen is polished, its apparent roughness could be similar to that of polished one. Nevertheless, the dents still substantially exist, it causes significant difference to the polished one.

4. Transgranular crack representing low propagation rate, for both ground and polished specimens is about 20μm deep, while after shot peening the depth is 40-50μm. According to He (1984) an average value of residual stress in low crack growth rate region is taken as mean stress. For ground specimen, fig 3 shows that the reverse bending fatigue limit and static bending strength lie on a straight line with a slope of 0.10. When mean stress is applied, the experimental fatigue limit of ground specimen finds its position near the line. Test result shows residual stress keeps unchanged for high strength steel at fatigue limit, so residual stress value before fatigue is adopted in this plot. Between polished and ground specimens the fatigue limit difference of 165MPa is due to surface topography. For shot peened then polished specimen, the increase of the fatigue limit can be resolved into three factors. The effect of the residual stress is evaluated with Goodman relation, it is 80 MPa. Since the trace of the tiny dent can still be clearly examined in this specimen, surface topography may presumptively provide two thirds of the value of polished one, it is about 100MPa. Thus, the remanined 150MPa should be attributed to the microstress relief. This value is associated with the enormous decrease of the half width. The fact is also valid for shot peened one. When the effect of the residual stress of the shot peened specimen is calculated with Goodman relation, the contribution of surface topography can easily be obtained. All of the effects of three factors are summarized in fig.4.

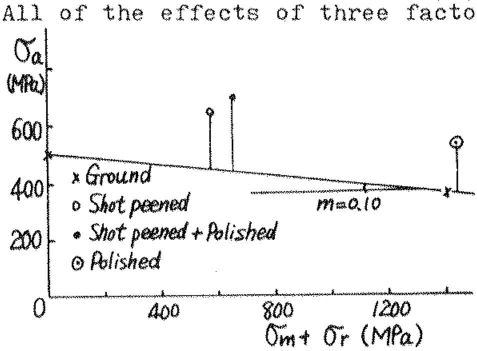

Fig.3 Goodman relation

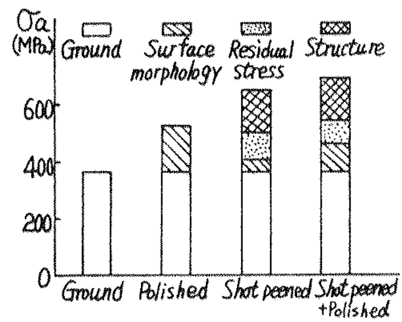

Fig.4 Three factors on fatigue limit

5. Now we may address some comments on former papers. Since residual stress which is effective in preventing crack growth is basically limited in a very thin layer, say 20-50μm in this steel. It is only required for high carbon hardened specimen to have high compressive residual stress in a very shallow surface layer. The effect of shot peening on structure improvement and microstress relief are more significant than mean stress or residual stress. While better surface finish is another contributing factor. If high intensity peening has been employed on a material to extend the compressive stress depth,which is deeper than transgranular

fracture depth, compressive stress in the inner part offers little effect on fatigue strength. On the contrary, it would be detrimental to surface topography and decreasing the fatigue limit. If the contributions of surface topograhy and microstress relief to the fatigue limit are not properly evaluated, the effect of residual stress would be greatly exaggerated. Assuming a line is drawn in fig.3 connecting the data of ground and peened specimens, one would find that its slope should be 0.34. The slope could be larger if the surface residual stress value is used. However, it is an approach of phenomenological view instead of intrinsic correlation.

CONCLUSIONS

1. In high carbon hardened steel, compressive residual stress in the surface layer of a smooth specimen prolongs transgranular crack depth and reduces the portion of intergranular fracture. It occurs within the range of 0.1mm. Thus, in an engineering sense residual stress can affect on fatigue crack initiation.

2. Average residual stress in low crack growth rate region bears an aspect as mean stress, the slope is about 0.10 in Goodman relationship.

3. Fatigue crack initiates at the bottom of grinding scratch or peening dent and then grows inwards. Shot peening lessens the surface detriment due to grinding and reduces microstress as well. Normally, these two factors are more significant than residual stress in high carbon steel.

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