Effect of Shot Peening on Fatigue Strength of Carbon Steel at Elevated Temperature

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Abstract

A study has been made on the effect of shot peening on fatigue strength at elevated temperature on 0.50% carbon steel. By means of bending rotating testing over the temperature range from 20 ℃ to 450 ℃, it was confirmed that shot peening increase the fatigue strength of specimens at room temperature due to work hardening and compressive residual stress at surface layer. And fatigue strength of shot peened specimens decrease with increasing testing temperature due to the reduction of the magnitude of residual stress. In comparison to annealed specimens, however, it was observed that the benefit of shot peening is disappeared up to 400 ℃ by work hardening.

KEY WORDS : Shot peening, Work hardening, Residual stress, Strain aging

INTRODUCTION

Shot peening is widely recognized as proven, cost-effective process to enhance the fatigue characteristics of metal parts, especially automotive parts [1]–[3]. By treatment of shot peening, engineers will be able to increase the life and the loading on both new and existing designs, without increasing size or adding weight to critical components. By the way sometimes shot peened machine parts are operated at elevated temperature. There is, however, no investigation which has considered the effect of shot peening at these temperature.

In this study, rotating bending fatigue tests over the temperature range from 20 ℃ to 450 ℃ were performed on 0.50% carbon steel in annealed and shot peened conditions. It was concluded that shot peening leads to an increase in 26% of fatigue strength compared to annealed conditions at room temperature due to work hardening and compressive residual stress at surface layer. And the fatigue strength of both annealed and shot peened specimens decrease to a minimum value at about 200 ℃, then increase to a maximum value at 375 ℃. It is well known that this behavior is caused by a strain aging during cyclic stressing [4]–[6]. And it is also confirmed that this effect of shot peening reduce over 400 ℃ as a result of relief of compressive residual stress, and an increase of notch effect due to uneven surface induced by shot peening. Further study, however, indicates that the benefit of shot peening is disappeared up to about 400 ℃ due to work hardening compared to annealed specimens.

EXPERIMENTAL PROCEDURES

The chemical composition of test specimens made of 0.50% carbon steel is shown in Table 1. Table 2 shows mechanical properties of test steel at room temperature. Three kind of specimens were prepared to clarify the effect of shot peening on fatigue strength at elevated temperature. Firstly, after machine finishing, the specimen was annealed by holding 685 ℃ for 2 h followed by gradually cooling at vacuum furnace, which is called annealed specimen. Secondly, specimens were shot peened by means of the centrifugal type machine with shot velocity of 48 m/s after annealing. And peening time was 120 s. Shot peening media was cut wire with a diameter of 0.5 mm and hardness of HV 412. Thirdly, shot peened specimens, which is called reannealed specimen, were carried out the annealing as mentioned above again to relieve the effective layer of shot peening, surface residual stress and work hardening. It is the purpose of this annealing to evaluate notch effect of specimens by uneven surface.

The fatigue tests were carried out with a rotating bending testing machine for elevated temperature at a frequency of about 60Hz. The surface residual stress of specimens after shot peening was measured by X-ray diffractmeter with 2θ - $\sin^2\Psi$ method. Stress distribution was obtained by repeating the X-ray measurement and electrochemical polishing successively.

Table 1. Chemical composition (wt%)

C	Si	Mn	P	S	Cu	Ni	Cr	N
0.51	0.27	0.68	0.016	0.023	0.17	0.06	0.17	0.007

Table 2. Mechanical properties

Tensile strength σ_B (MPa)	Elongation δ (%)	Reduction of area ϕ (%)	Hardness (HV)
662	24	51	174

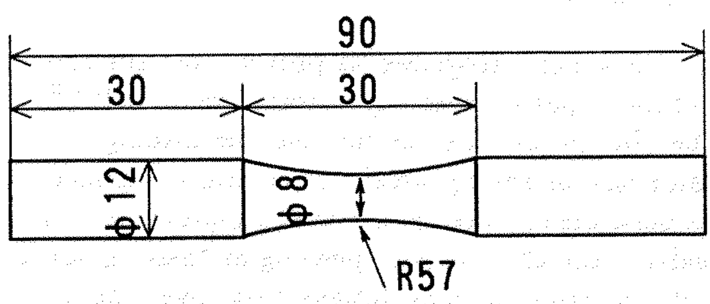

Fig. 1. The geometry of specimens

RESULTS AND DISCUSSION

Fig. 2 shows surface residual stress and hardness distributions of annealed and shot peened specimens. There exists remarkable compressive residual stress of 400MPa within the depth of 200μm by shot peening. And surface hardness of the shot peened specimens is HV 210, which results in HV 40 increase as compared to as annealed specimens.

Fig. 3 shows the results of rotating bending fatigue test of each conditioned specimens at room temperature. The fatigue strength for 10^7 cycles of shot peened specimens was 330MPa

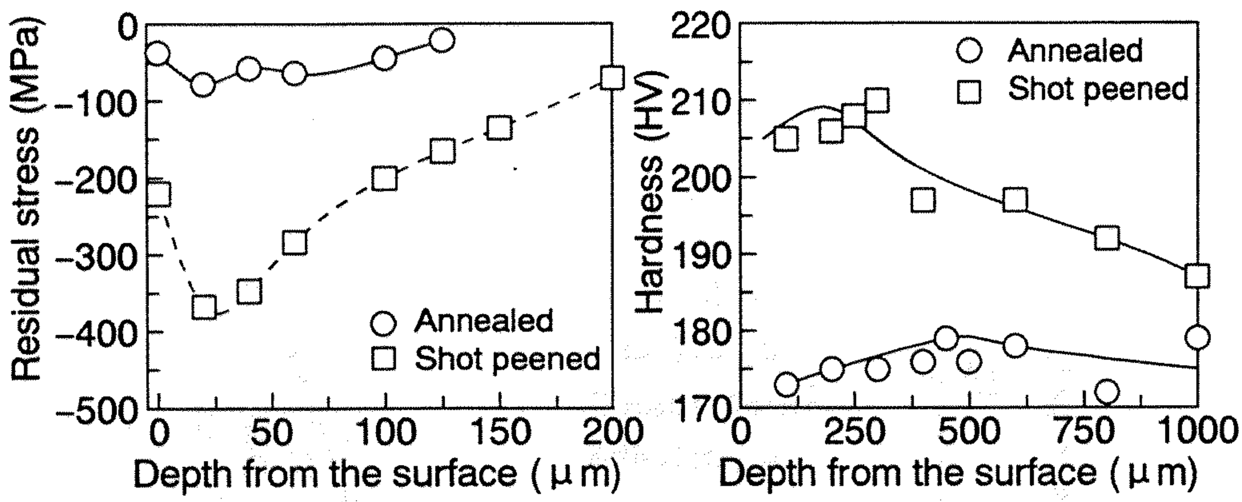

Fig. 2. Residual stress and hardness distributions of each specimens

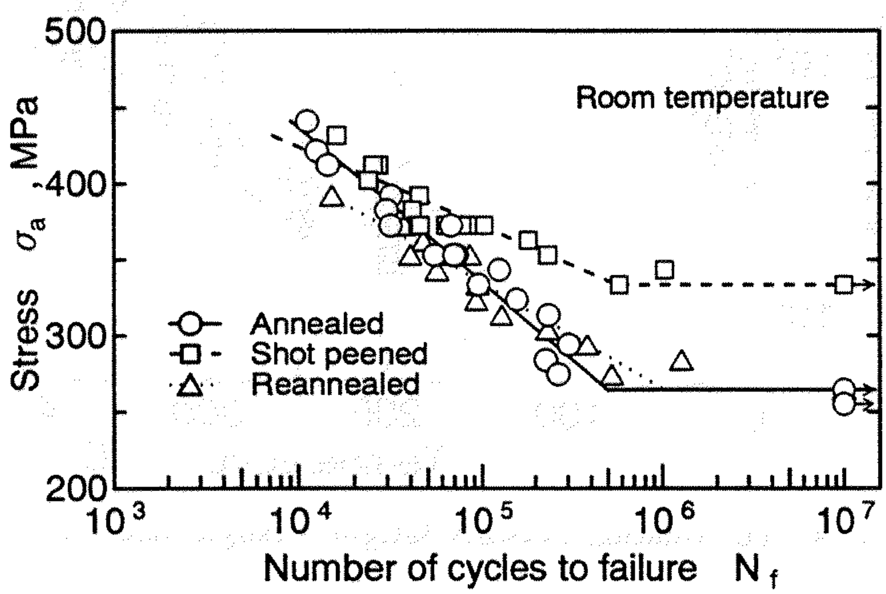

Fig. 3. S-N curves for each specimens at room temperature

and those of annealed and reannealed specimens were both 260MPa. It means that the shot peening gives 26% increase in bending fatigue limit and the harmful notch effects due to uneven surface after shot peening are disappeared at room temperature.

To clarify the effect of testing temperature on fatigue strength for each specimens, fatigue test with 5 to 7 pieces of each specimens were carried out at the same stress amplitude. The stress where 10^5 life is obtained was selected from the previously shown S-N curve. The stress for annealed and reannealed specimens was 353MPa and 373MPa for shot peened specimens.

The relation between fatigue strength and testing temperature is shown in Fig. 4. According to this figure, it was confirmed that fatigue strength of each specimens takes a maximum value at about 375 ℃ and a minimum value at about 200 or 250 ℃. It is well recognized that this behavior is caused by a strain aging during cyclic stressing. No difference were observed in the increasing rate of fatigue life at maximum value on 375 ℃ between annealed and shot peened specimens. On the other hand, the increasing rate of reannealed specimens at that temperature was lower than that of another specimens. It is considered that the sensitivity

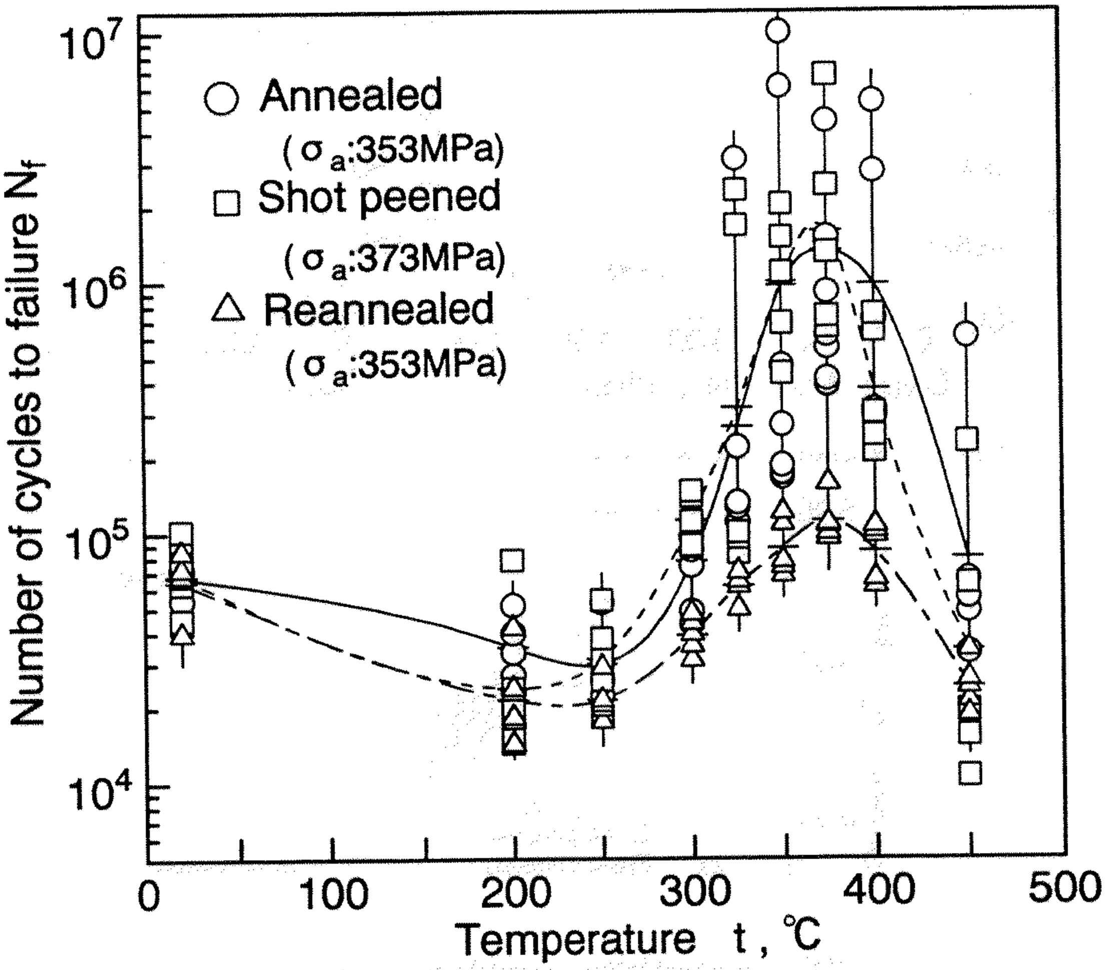

Fig. 4. The relation between fatigue strength and testing temperature

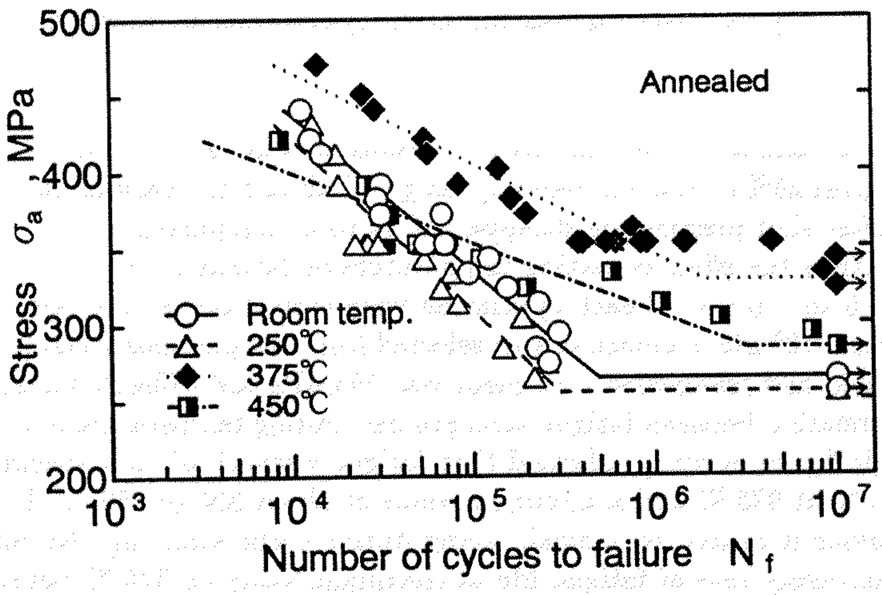

Fig. 5. S-N curves for annealed specimens

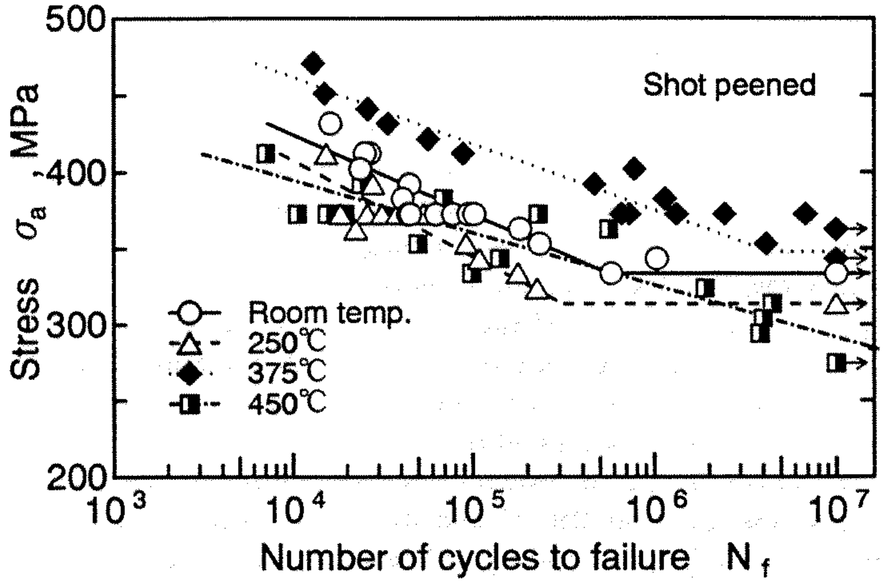

Fig. 6. S-N curves for shot peened specimens

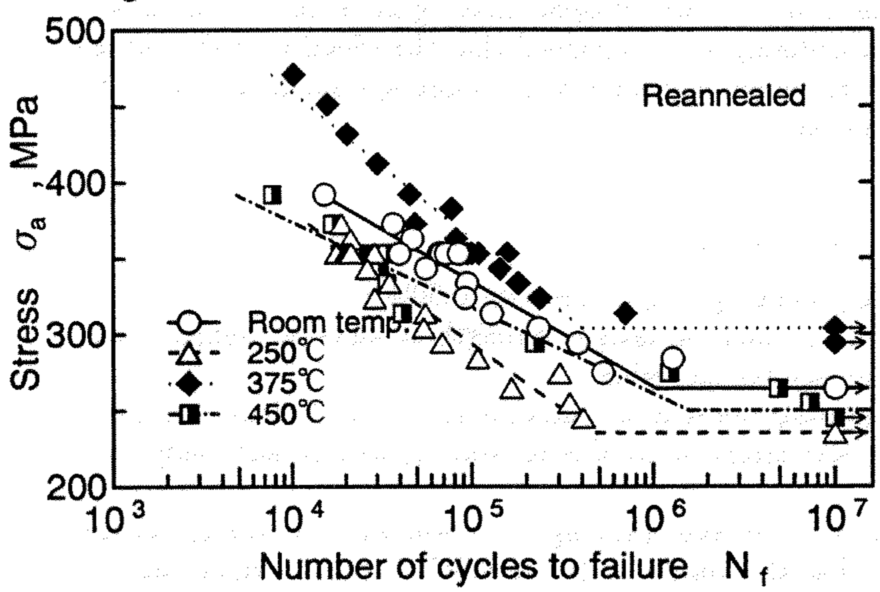

Fig. 7. S-N curves for reannealed specimens

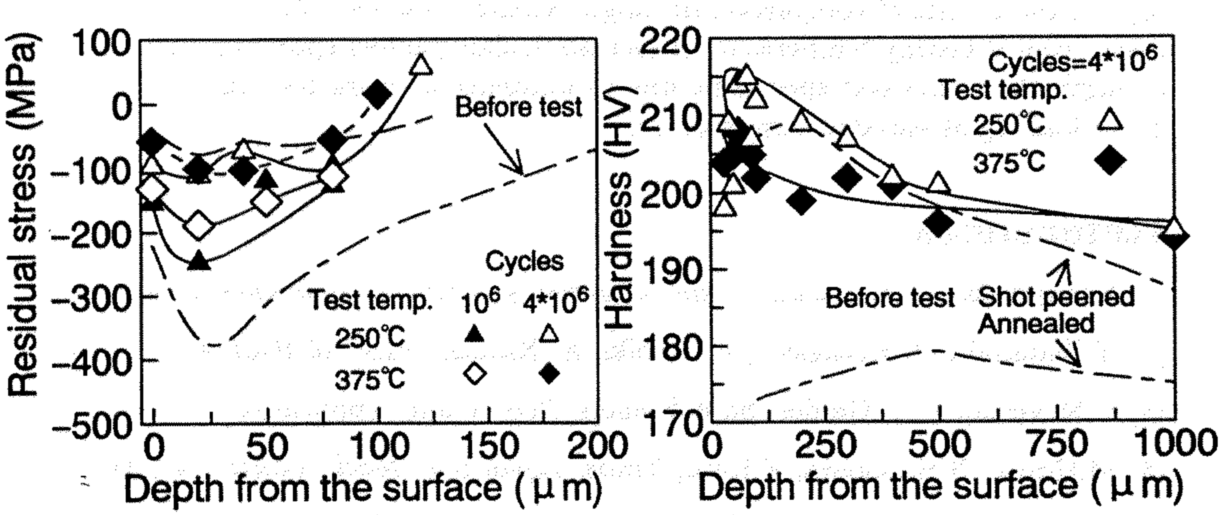

Fig. 8. The change of residual stress and hardness distributions after fatigue test

for notch effect due to relief of the surface compressive residual stress and work hardening at reannealed specimens decreases fatigue life with increasing testing temperature.

Fig. 5, Fig. 6 and Fig. 7 show the results of fatigue test of each specimens at 250 ℃, 375 ℃, 450 ℃ and room temperature. It is confirmed that the fatigue properties at 375 ℃ is highest compared to that at another testing temperature. This means that a strain aging mainly contribute to increase of fatigue strength. The fatigue strength of the annealed and reannealed specimens at 450 ℃ indicated almost same strength at room temperature. On the other hand, that of the shot peened specimen at 450 ℃ temperature is lower than that at room temperature, especially at high number of cycles. It is mainly considered that this results is due to relief of residual stress as mentioned above, and the sensitivity of notch effect increase by corrosion with increasing temperature.

Fig. 8 shows the change of residual stress and hardness distributions after cyclic loading for shot peened specimens at 250 ℃ and 375 ℃. It was confirmed that the residual stress decrease with increasing cyclic loading and the residual stress almost is relieved down to same value of annealed specimen in case of specimens tested at 375 ℃. In the results of hardness distribution, however, even if cyclic loading increases, hardness at the surface layer hardly decreases. Accordingly, it is concluded that the effective of shot peening at elevated temperature are slightly remained compared to annealed specimens due to work hardening, even if residual stress is relieved.

CONCLUSIONS

Rotating bending fatigue tests on 0.50% carbon steel were carried out to investigate the effect of shot peening on fatigue strength at elevated temperature. The conclusions obtained in this study are the following ;

(1) Shot peening leads to an increase in 26% of fatigue strength compared to annealed conditions at room temperature due to work hardening and compressive residual stress at surface layer.

(2) The effective of shot peening decreased with increasing testing temperature. It is mainly considered that this results is due to relief of residual stress, and the sensitivity of notch effect increase by corrosion with increasing temperature

(3) As the results of comparison of fatigue strength between annealed and shot peened specimens, even if testing temperature is increased, shot peened specimens indicated higher fatigue strength than annealed specimens due to existence of work hardening, which remained after cyclic loading at elevated temperature.

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