EFFECT OF SHOT PEENING ON BENDING FATIGUE STRENGTH OF SPRING STEEL SPECIMENS CONTAING AN ARTIFICIAL SURFACE DEFECTS

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ABSTRACT

Effects of shot peening on the bending fatigue strength of spring steel (SUP9A) specimens with 500*HV* containing an artificial small hole were investigated. Shot peening (SP) and stress shot peening (SSP) were carried out with specimens containing an artificial drilled hole of 0.2, 0.3, 0.4 and 0.8 mm diameter. Then, bending fatigue tests were carried out with the specimens with a stress ratio of zero. The bending fatigue limits of specimens containing a drilled hole were increased 34-44 % by SP or 68-77 % by SSP, respectively. The specimens containing a drilled hole under 0.2-0.3 mm in diameter had very high fatigue limits almost equal to those of shot-peened non-defect specimens. From these results, it can be concluded that a drilled hole under 0.2-0.3 mm in diameter can be made non-damaging by SP or SSP.

KEY WORDS

Shot peening, Stress shot peening, Surface defect, Non-damaging, Bending fatigue limit, Drilled hole, Residual stress.

INTRODUCTION

The surface detects have danger of decreasing fatigue strength in automobile parts such as a spring that the largest stress occurs at surface. If surface defects can be made non-damaging crack by shot peening, or fatigue strength having surface detects can be improved, it can be achieved increased reliability and low cost. So far it has been carried out a lot of research to improve fatigue strength for automobile parts from the viewpoint of energy conservation and environment problems. There are mainly two popular ways to increase fatigue limit: (a) increase the hardness of materials, and (b) introduce a large compressive residual stress in components. However, for technique (a) because the Vickers hardness (HV) of currently-used automobile springs is very high, approximately, 600HV, it is difficult to increase the hardness further. Moreover, if the HV is increased further, materials will be too sensitive for corrosion fatigue and hydrogen embitterment. For technique (b), shot peening is a very popular technique for inducing compressive residual stress. Shot peening is especially useful for components that are subjected to a cyclic load with a

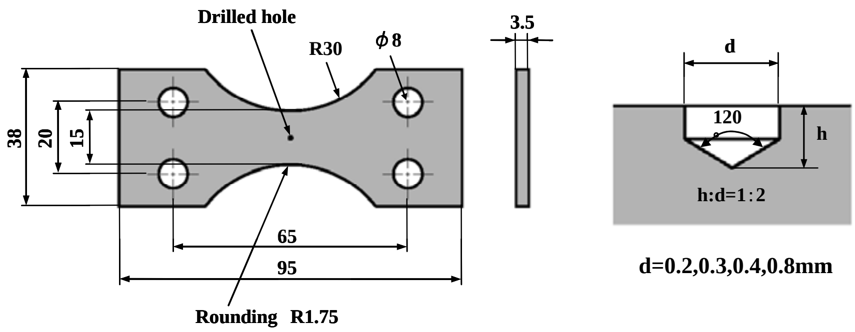
stress ratio R≧0. For this reason, in order to improve fatigue limit, shot peening has been widely used, and its various techniques have been developed (K.Ando,2005;H.Ishigami,2000). However, there are few studies regarding the effects of shot peening on materials containing an original surface defect.
In this study, in order to find and propose a method to improve fatigue limit and to make the surface detect non-damaging, we conducted shot peening on spring steel specimens containing an artificial small hole, and we carried out a plane-bending fatigue test using specimens.

EXPERIMENTAL PROCEDURE

The spring steel used in the present study was Japanese Industrial Standards (JIS) SUP9A. Table 1 shows its chemical composition (wt.%). Fig.1 shows the shape and dimension of a specimen and a small hole. After the machining of a specimen, a drilled hole was introduced at its center. Next, the specimens were oil-quenched at 860℃ and tempered at 420℃. The Vickers hardness of the specimens after heat treatment was 500HV.
The specimens used in the present study were non-defect specimens and specimens having an artificially-drilled hole, with the ratio of diameter (d) and depth (h) being h=1/2d, as shown in Fig.1(b). The diameters of the drilled holes were 0.2mm, 0.3mm, 0.4mm and 0.8mm, respectively.

Table.1 Chemical composition of SUP9A (wt%)

Material	C	Si	Mn	P	S	Cu	Ni	Cr
SUP9A	0.57	0.25	0.86	0.022	0.019	0.2	0.11	0.82



(a) Plane-bending specimen. (b) Drilled hole.
Fig.1 Shape and dimension of specimen and hole.

After heat treatment, we conducted shot peening on non-defect specimens and specimens with a small hole. Table 2 shows the shot peening conditions adopted in this study. The shot peening was carried out with a direct pressure peening system. The shot used was conditioned cut wire of steel with diameter of 0.67mm and a hardness of 660HV.
In this study, stress shot peening was also carried out. A four-point bending system was used to apply stress. The stress on the surface was measured using a strain gage. The tensile stress applied to the specimens was 1000MPa (H.Okada,2004). In this study, normal shot peening without stresses is called SP, and stress shot peening is called SSP.
The residual stress distributions induced by SP and SSP are shown in Fig.2, where σ_s, σ_{max} and d_0 are the compressive residual stress at the surface, the maximum

compressive residual stress and the distance from the surface to the zero residual stress point (crossing point), respectively. The σ_{max} and theσ_s induced by the SP was about -750MPa and -600MPa, respectively. The d_0 was 0.30mm. The σ_{max} and theσ_s were remarkably increased by SSP.

Table 3 shows surface roughness before and after SP and SSP. The value of surface roughness increased after both. However, these values of surface roughness were much smaller than the depth of the artificial drilled hole (0.1-0.4mm).

Fatigue tests were carried out on the above specimens. The plane-bending fatigue testing machine was used. The fatigue test conditions were a stress ratio of R=0 and a cyclic frequency of 50Hz. The stress wave was a sine wave. The fatigue limit was defined as the maximum stress amplitude under which the specimen endured 10^7 cycles. A scanning electron microscope (SEM) was used for observations of the fracture surface of specimens.

Table.2 Shot peening condition

Peening machine	Direct pressure peening
Air pressure	0.62MPa
Shot diameter	0.67mm
Shot hardness	600HV
Nozzle diameter	5mm
Shot time（one side）	40s
Shot distance	100mm
Coverage	300%
Arc height	0.50mmA
Pre-stress（only SSP）	1000MPa

Table.3 Surface roughness （μm）
JIS B 0601（1994）

	Non-SP	SP	SSP
Ra	0.7	2.7	3.5
Ry	5.0	21.6	26.8

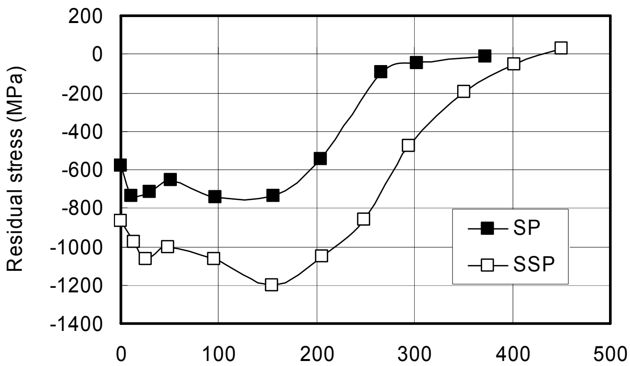


Fig.2 Residual stress distribution.

EXPERIMENTAL RESULTS AND DISCUSS

Effect of shot peening on bending fatigue limit

Figs.3(a)~(e) show the relationship between the stress amplitude (σ_a) and the number of cycles to failure (N_f). The symbol ○ indicates a non-shot peened specimen (non-SP). The Symbols ■ and ▲ indicate shot peened (SP) and stress shot peened (SSP) specimens, respectively. The asterisk symbols indicate that the spacemen fractured elsewhere than on the drilled hole. The arrow indicates that the fracture had not occurred when the test was terminated at 10^7 cycles. The values of the fatigue limit are indicated in Figs.3 (a)-(e). By shot peening, the fatigue limit and fatigue life of specimens dramatically increased.

Size of drilled hole which can be made non-damaging by shot peening

The size of defects which can be non-damaging by SP or SSP was evaluated by the following two criterions. (a) Fatigue limit of specimens containing a surface defect increased by SP or SSP within 5% of the fatigue limit of a non-defect-SP or non-defect-SSP specimen. (b) Specimens containing a surface defect which subjected to SP or SSP fractured outside the original surface defect. Table 4 shows the size of defects which can be non-damaging by SP or SSP evaluated by the criterions. Fig.4 shows the increasing

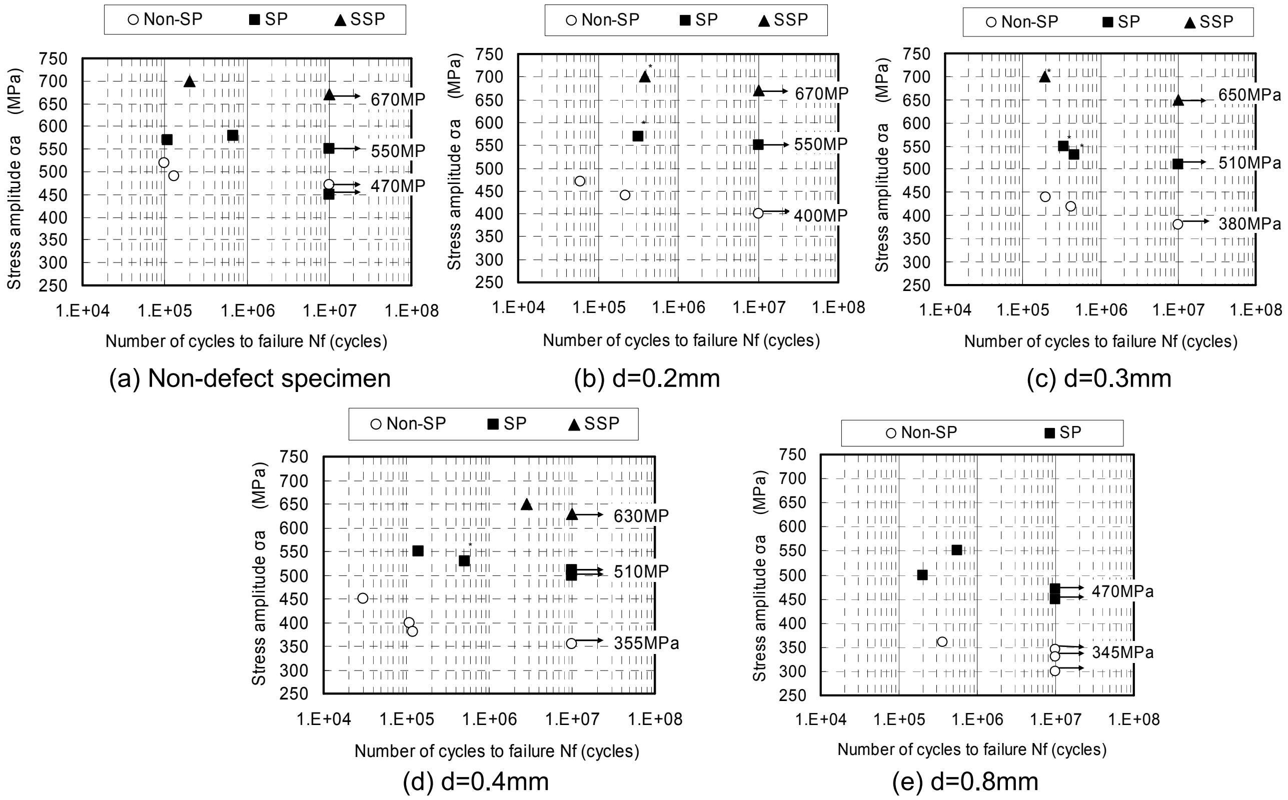


Fig.3 S-N curve for plane bending fatigue test

Table 4 Size of defects which can be non-damging by SP or SSP

	Criterion (a) Based on fatigue limit	Criterion (b) Based on failure origin
SP	0.2mm	0.3mm
SSP	0.3mm	0.3mm

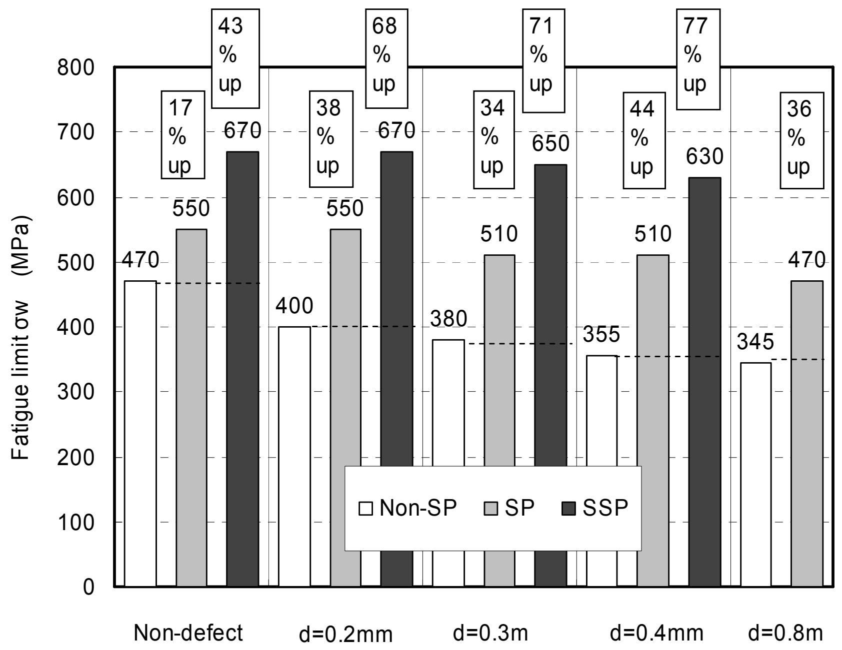


Fig.4 Improvement ratio of fatigue limit

ratio of the fatigue limit for each specimen. The fatigue limit was increased 34-44% and 68-77%, respectively by SP and SSP compared with Non-SP specimens. To increase fatigue limit of specimens containing surface defects, it is effective to make the values of σ_s and σ_{max} large. The sizes of drilled holes which can be made non-damaging based on criterion (a) are 0.2mm by SP and 0.3mm by SSP.

Fig.5 shows the results of the plane-bending fatigue tests, which show the relationship between the stress amplitude and the diameter of holes. The solid symbols represent the specimens fractured during fatigue tests. The open symbols represent the specimens which did not fracture at up to 10^7 cycles, where the maximum stress amplitude corresponds to the fatigue limit. The asterisk symbols indicate that the specimen fractured elsewhere than on the drilled hole. In 0.2mm-holed-SP, 0.3mm-holed-SP, 0.2mm-holed-SSP and 0.3mm-holed-SSP specimens, all specimens fractured elsewhere than on the drilled hole. Therefore, it was found that drilled holes under 0.3mm in diameter could be made non-damaging by SP and SSP based on criterion (b).

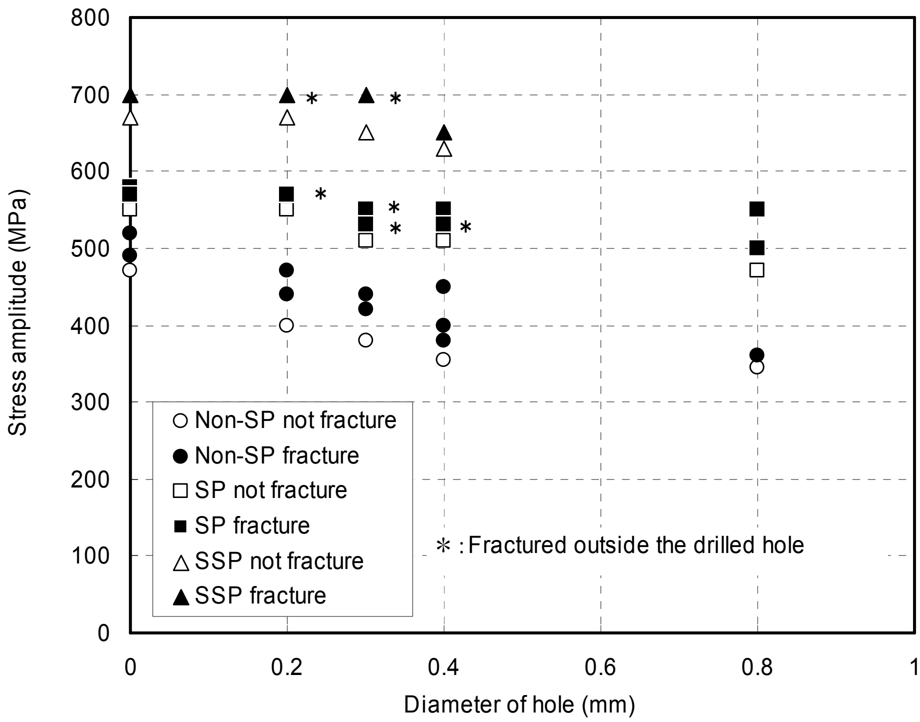


Fig.5 Relationship between stress amplitude and diameter of hole (SUP9A, 500HV, plane bending, R=0)

Observation of fatigue fracture surface

Fig.6 shows SEM images of fracture surfaces for specimens having drilled holes with diameter of 0.2mm, 0.3mm, 0.4mm and 0.8mm. The broken lines in Fig.6 show the front of a fatigue crack. It can be seen that fatigue crack growth was small in Non-SP specimens. On the other hand, fatigue cracks in SP and SSP specimens propagated deeper than those in the Non-SP specimens. It seems that compressive residual stress reduced the stress intensity factors at crack tip.

The small holes were deformed by shot peening. The fatigue limit of the materials with surface defects was increased mainly by shot peening because of compressive residual stress. Deforming the surface defects also contributed to increasing the fatigue limit and making the defect size small.

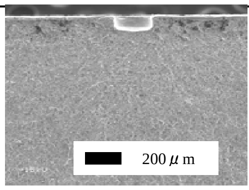
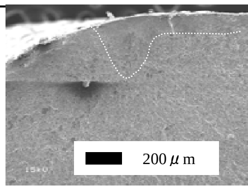
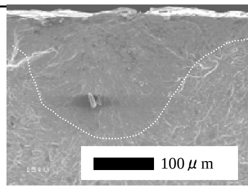
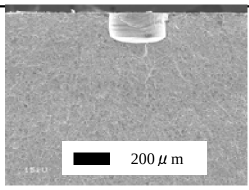
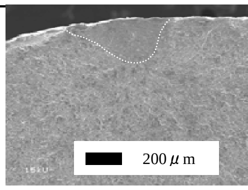
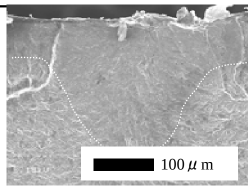
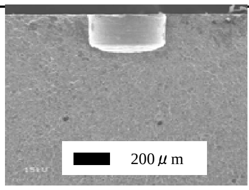
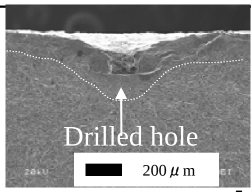
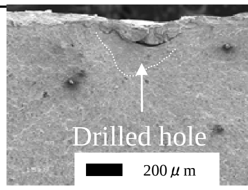
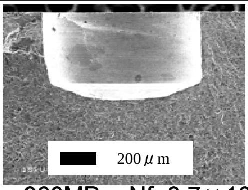
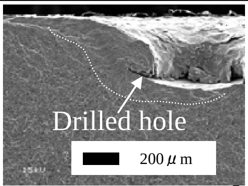
d（mm）	Non-SP	SP	SSP
0.2	 σa=440MPa, Nf=2.2×10^5	 σa=570MPa, Nf=3.2×10^5	 σa=700MPa, Nf=3.8×10^5
0.3	 σa=420MPa, Nf=4.2×10^5	 σa=530MPa, Nf=4.7×10^5	 σa=700MPa, Nf=1.9×10^5
0.4	 σa=380MPa, Nf=1.2×10^5	 σa=550MPa, Nf=1.4×10^5	 σa=650MPa, Nf=2.81×10^6
0.8	 σa=360MPa, Nf=3.7×10^5	 σa=500MPa, Nf=2.0×10^5	

Fig.6 Fatigue fracture surface

CONCLUSION

(1) The fatigue limit of spring steel specimens containing a surface defect was increased by shot peening. Compared with non-shot peening (Non-SP) specimens, SP specimens increased 34-44％, SSP specimens increased 68-77％.

(2) An artificial drilled hole under 0.2–0.3mm in diameter can be made non-damaging by SP or SSP.

(3) The fatigue limit of materials with surface defects was increased by shot peening because of compressive residual stress. Deforming the surface defects also contributed to increasing the fatigue limit because stress concentration factors at the edge of holes decreased by the deformation.

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