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The Effect of Compressive Residual Stresses of Two-stage Shot Peening for Fatigue Strength of Spring Steel

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Abstract : Recently the steel parts used in automobiles are required to be used under high stress more than ever before due to the need of keeping the weight down. To achieve this requirement of the high strength steel, it must be necessary to decrease inclusion contents and surface defects as like decarburization, surface roughness etc. In this study, the surface conditions are measured to know the influence on fatigue properties by two cases of two-stage shot peening and single-stage shot peening. And for this study, three kinds of spring steel (JISG4081-SUP7, SAE 9254 and DIN 50CrV4) are shaped. This study shows the outstanding improvement of fatigue properties at the case of two-stage shot peening in the rotating bending fatigue test and it results from (1) decreasing the surface roughness (2) unchanging the surface hardness (3) increasing the compressive residual stress. Moreover, results also show fatigue failures originated at the inclusion near the surface, and this inclusion type is turned out to be an alumina of high hardness.

Key words : two-stage shot peening, compressive residual stress, rotating bending fatigue test, fatigue strength, fatigue life

1. Introduction

In recent, it is increasing that a reduction of the mechanical components and structures weight is needed. To achieve this, the usage of high strength materials have been increased. But, it causes degradation of the fatigue properties [1, 2].

Shot peening is widely used for the improvement of the fatigue properties of material. This surface treatment can prolong the fatigue life and enhance the fatigue strength as well. Compressive residual stress induced by shot peening are the major factor improving fatigue behavior [3].

Many researchers have investigated the effects of the compressive residual stress by single-stage shot peening but scarcely studied two-stage shot peening [4]. However, it has been, recently, reported that two-stage shot peening improves the fatigue properties more than single-stage shot peening [5].

In this study, rotating bending tests are conducted on single-stage shot peened specimens and two-stage shot peened specimens to investigate the effects of two-stage shot peening on fatigue life, and fracture surfaces are compared.

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2. Experiments

The materiasl used in this study were three kinds of spring steel (SAE 9254, DIN 50CrV4 and JISG 4081-SUP 7). The chemical composition and mechanical properties were summarized in Table 1 and Table 2. In this table, Brinell hardness was measured at 100 μm from surface. The specimen configuration for rotating bending test was shown in Fig. 1.

To know the influence on fatigue life by shot peening, single-stage shot peened specimens and two-stage shot peened specimens were made. The conditions of shot peening were shown in Table 3.

The distribution of residual stress was measured with X-ray stress measurer (RIGAKU-MSF2M). The measuring conditions of residual stress distribution are tabu-

Table 1. Chemical composition (wt, %)

	C	Si	Mn	P	S	Cu	Cr	V
50CrV4	0.50	0.27	0.82	0.02	0.005	–	0.10	0.117
SAE9254	0.55	1.36	0.7	0.01	0.002	–	0.68	–
SUP7	0.59	0.19	0.84	0.012	0.003	0.03	–	–

Table 2. Mechanical properties of specimen

Material	Tensile Strength (Mpa)	Hardness(H_B)		Elongation (%)	Reduction of area (%)
		after Quenching	after Tempering		
50CrV4	1795	2.5	2.75	9.4	35.7
SAE9254	1764	2.3	2.75	9.4	36.0
SUP7	1778	2.35	2.75	11.4	41.9

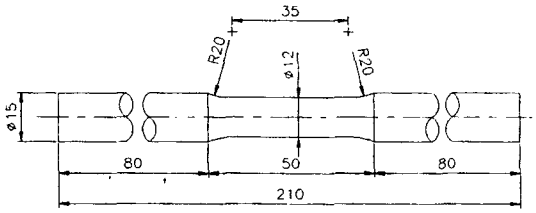


Fig. 1. Dimensions of Specimen (unit: mm).

Table 3. Conditions of Shot-peening

Condition	1 Stage Shot-Peening	2 Stage Shot-peening
Impeller Dia	490 mm	360 mm
Blades Width/Q'ty	90 mm/6 pcs	60 mm/6 pcs
r.p.m	2200 r.p.m	3000 r.p.m
Shot-Ball Dia.	0.8 mm	0.6 mm
Time	24 sec.	10 Min.
Arc Height (Alman A-Stip)	0.375 mm	0.305 mm
Coverage	85%	90%

Table 4. Measuring condition of residual stress

X-Ray Diffration	Condition	
X-Ray Source	Taget	Cr-V
	Voltage	30 KV
	Current	10 mA
Ψ	0°, 15°, 30°, 45°	
2θ	140°~170°	
Diffration	Scintillation Counter	

lated in Table 4.

The fatigue tests were performed in air at room temperature on the Ono type rotating bending test machine. The speed of this machine was 3,400 r.p.m.

3. Results and Discussion

Fig. 2 shows the distribution of residual stress produced by shot peening. In each case, the maximum value of compressive residual stress induced by two-stage shot peening is 300~600 MPa higher than that by single-stage shot peening. In addition, its depth is 25~50 μm deeper.

Fig. 3 shows the comparison of surface roughness between two cases (two-stage shot peening and single-stage shot peening). After single-stage shot peening, the value of roughness R_a is 1.798~2.37 μm and its maxi-

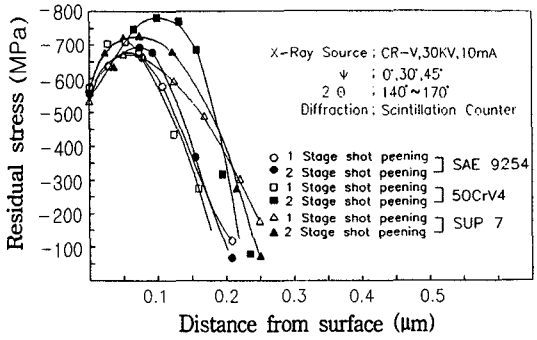


Fig. 2. Residual stress distributions produced by Shot-peening (SAE 9254, 50CrV4, SUP 7).

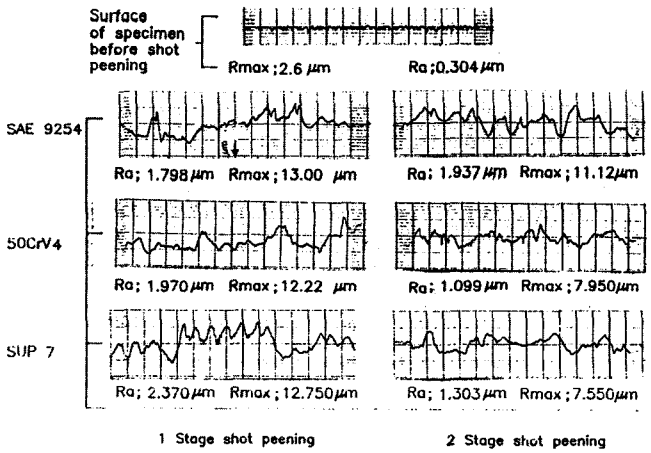


Fig. 3. Roughness pattern of shot peened specimen.

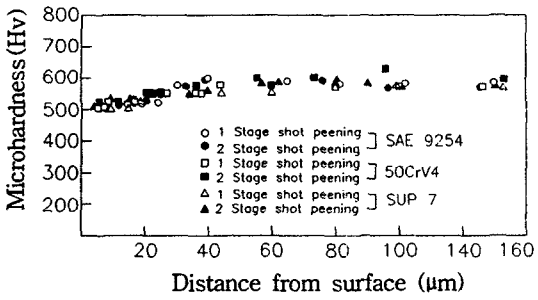


Fig. 4. Hardness distributions produced by Shot-peening(SAE 9254, 50CrV4, SUP 7).

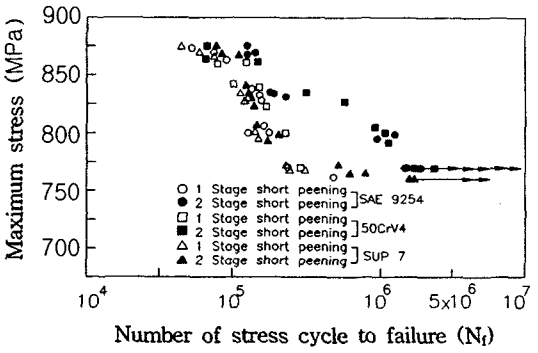


Fig. 5. Rotating bending fatigue S-N curves for SAE 9254, 50CrV4, SUP 7 specimen.

mum R_{max} is 12.22~13.00 μm. However, the roughness of two-stage shot peened specimen decreases by R_a= 1.099~1.937 μm and R_{max}=7.55~11.12 μm.

Although two-stage shot peened specimen has higher compressive residual stress and lower roughness, the values of Vickers hardness (HV) of two case specimens are almost same (HV=503~637) as shown Fig. 4.

Fig. 5 shows the results of rotating bending fatigue tests for SAE 9254, 50CrV4 and SUP 7 specimen. In the part of high stress amplitude, fatigue lives of two-stage shot peened specimens are similar to single-stage shot peened specimens, because the major factor of fracture is the value of tensile strength when high stress amplitude is loaded on specimen. However, fatigue lives remarkably increase with stress amplitude decreasing because fatigue fracture process is affected by the compressive residual stress. Two-stage shot peened specimen are, thus, more durable against fatigue loading.

Fig. 6, 8 and 10 show fractographical SEM analyses of single-stage shot peened specimens and Fig. 7, 9 and 11 show fractographical SEM analyses of two-stage shot peened specimens. Fracture originates from the surface in all cases and arc-shaped white area, called fish-eye, is observed at the origin of fracture. In the cases of two-stage shot peened specimens, white area is wider than the case of single-stage shot peened specimens,

Fig. 6. SEM photographs of fracture surface around crack initiation point (SAE 9254 under 1 stage shot-peened).

Fig. 7. SEM photographs of fracture surface around crack initiation point (SAE 9254 under 2 stage shot-peened).

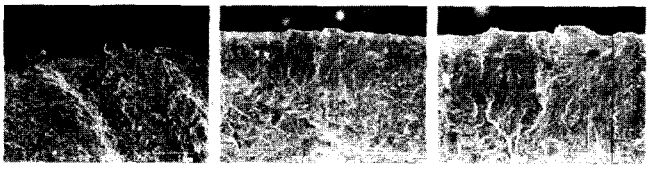


Fig. 8. SEM photographs of fracture surface around crack initiation point (50CrV4 under 1 stage shot-peened).

Fig. 9. SEM photographs of fracture surface around crack initiation point (50CrV4 under 2 stage shot-peened).

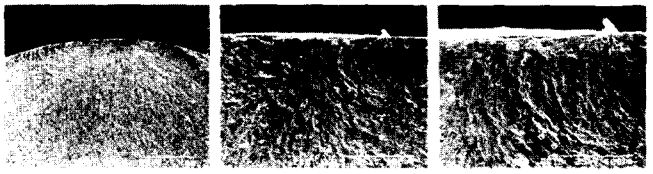


Fig. 10. SEM photographs of fracture surface around crack initiation point (SUP 7 under 1 stage shot-peened).

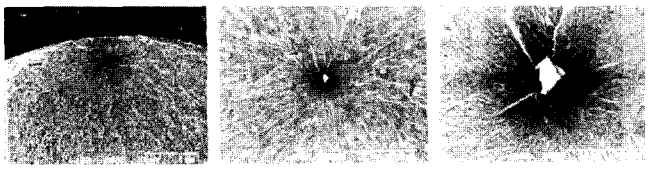
Fig. 11. SEM photographs of fracture surface around crack initiation point (SUP 7 under 2 stage shot-peened).

because the position having maximum compressive residual stress is deeper from surface [6, 7].

In the several cases of the fracture surface of two-

Specimen : SAE 9254
Condition : two-stage shot-peening
Fatigue Limit : 800MPa
Number of Cycles : 240,000 r.p.m.

Fig. 12. SEM photographs of fish eye (nonmetal) fracture region under 800 MPa.



Specimen : DIN 50CrV4
Condition : two-stage shot-peening
Fatigue Limit : 830MPa
Number of Cycles : 77,600 r.p.m.

Fig. 13. SEM photographs of fish eye (nonmetal) fracture region under 830 MPa.

stage shot peened specimen, fatigue failures originated at inclusion near surface as shown in Fig. 12, and Fig. 13. This inclusion type is turned out to be an alumina of high hardness. Fatigue lives were significantly decreased because of this inclusion [8].

4. Conclusions

To investigate the effects of two-stage spot peening on fatigue life, rotating bending tests are conducted on single-stage shot peened specimens and two-stage shot peened specimens. The materials are SAE9254, DIN50-CrV4 and JISG4081-SUP7 steel. The following conclusions have been drawn.

1) The maximum value of compressive residual stress induced by two-stage shot peening was 300~600 MPa higher than single-stage shot peening and its depth was 25~50 μm deeper.

2) The value of roughness R_a decreased 28% and its maximum R_{max} decreased 30% by two-stage shot peening.

3) The values of Vickers hardness (HV) were almost same (HV=503~637) in all cases.

4) Fatigue lives and fatigue strength remarkably increased by two-stage shot peening because of the compressive residual stress.

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