Influences of Mechanical Properties and Retained Austenite Content on Shot-peening Characteristics

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Preface

The shot-peening process is used for many parts to improve their fatigue strength. Some major applications of shot-peening include surface roughing, hardening and compressive residual stress application. Compressive residual stress is considered the most effective method for improving the fatigue strength and, the most important compressive residual stress is maximum compressive residual stress.[1) and 2)]

The maximum compressive residual stress is, in general, limited by the yield stress of the shot-peened material. According to the studies made by Tange, et al., the maximum compressive residual stress applied to spring steels by shot-peening is reported to be about 50-60% of the yield stress.[3)] In case of materials containing much retained austenite such as carburized steels, however, their mechanical properties as well as the compressive residual stress caused by expansion of deformation-induced martensite should be considered.

In this study, materials with different mechanical properties and retained austenite contents were used to determine the influences of mechanical properties and retained austenite content on shot-peening characteristics.

2 Specimens and test method

2.1 Specimens

In this study, JIS chrome molybdenum steel and chrome steel based materials with different carbon contents and heat treatment conditions were used. Table 1 shows carbon contents, heat treatment conditions, mechanical properties and retained austenite contents of at surface of specimens. Fig.1 shows shape and dimension of specimen.

Table 1. Retained austenite contents and mechanical properties of specimens

Symbol	Carbon content (wt %)	Heat treatment conditions	ó0.2 (MPa)	óB (MPa)	Hardness (HV)	Retained austenite (vol %)
0.2% C	0.2	Quenching-453K tempering	1224	1510	485	3.0
0.4% C	0.4	Quenching-453K tempering	1488	2062	609	4.9
0.6% C	0.6	Quenching-453K tempering	1470	2473	697	9.0
0.8% C	0.8	Quenching-453K tempering	1090	2049	737	19.7
453K TEMPER	0.8	Quenching-453K tempering	1131	1808	720	21.2
573K TEMPER	0.8	Quenching-573K tempering	1833	2083	612	5.6
SUB-ZERO	0.8	Quenching-Subzero-453K tempering	–	1721	790	1.6
QUENCH	0.8	Quenching	–	–	808	24.2

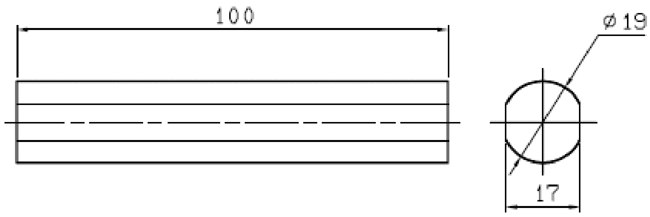

Fig.1 Shape and dimension of specimen

2.2 Shot-peening conditions

The specimens were shot-peened under the conditions specified in Table 2. In this study, HV930 and HV700 media were used to shot-peen them to also determine the influence of shot-peening conditions on the results.

Table 2. Shot-peening conditions

Symbol	Media	Hardness (HV)	Diameter (mm)	Method	Air pressure (MPa)	Coverage (%)	Arc height (mmA)
SP-930	CCW	930	0.3	Direct pressure	0.5	300	0.384
SP-700	CCW	700	0.6	Direct pressure	0.3	300	0.510

2.3 Evaluation method

Evaluation of hardness was used by Vickers hardness tester. Evaluation of residual stress and retained austenite were used by X-ray diffractometer. For depth direction of residual stress and retained austenite, these were measured after achieving the targeted depth by electrolytic-polishing. As a result, we gained residual stress distribution. In this study, we define the parameter of shot-peening characteristics as below.

1) Surface hardness is hardness at top surface.

2) Surface retained austenite is retained austenite at top surface.

3) Maximum residual stress is maximum value of residual stress distribution.

3 Test results

3.1 Surface hardness

Fig.2 shows typical surface hardness values obtained in this study.

As regards influences of shot-peening conditions, the surface hardness of specimens shot-peened with SP-930 grew harder as a result.

As regards influences of properties of the shot-peened material, the highest surface hardness about HV1130 was obtained by QUENCH specimens shot-peened with SP-930. SUB-ZERO specimens had harder surfaces than non-sub-zero-treated, 453K TEMPER specimens before shot-peened but their shot-peened surface hardness values were almost equivalent.

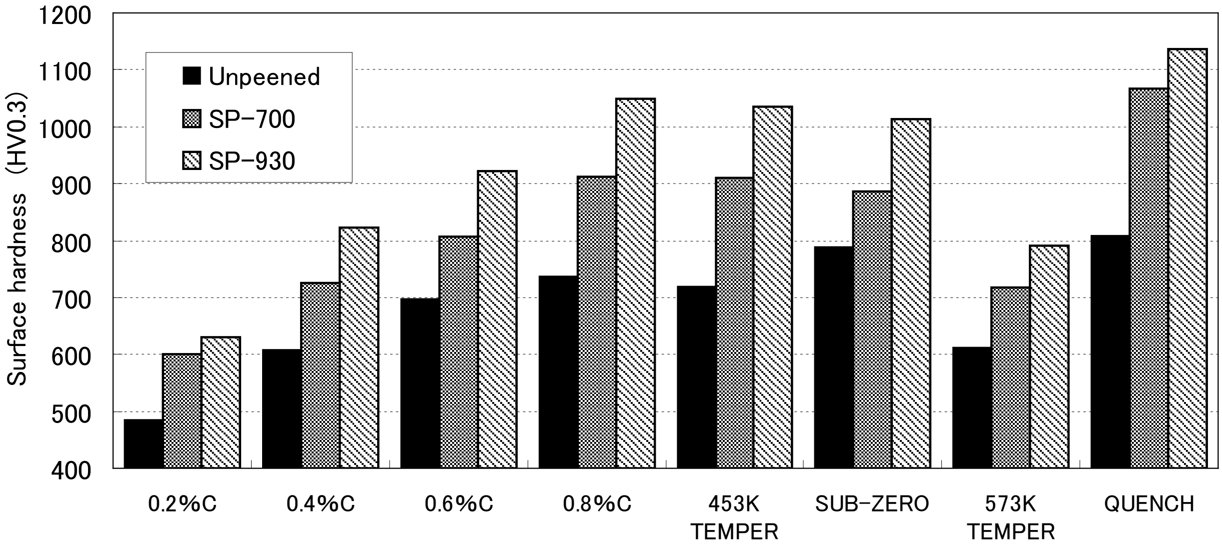

Fig.2 Surface hardness as affected by carbon content, peening and prior heat treatment.

3.2 Surface retained austenite

Figure 3 shows the surface retained austenite contents obtained in this study.

As regards influences of properties of the shot-peened material, the higher carbon content tended to have a greater effect to increase the resultant retained austenite content. The retained austenite content of a 453K TEMPER specimen, which had been about 21% by volume, was reduced to about 5% by volume by sub-zero treatment. The retained austenite contents of all specimens were radically reduced by shot-peening.

As regards influences of shot-peening conditions, SP-930 had a greater effect to reduce the retained austenite content.

3.3 Residual stress

Fig. 4 shows the maximum compressive residual stresses obtained in this study.

As regards influences of properties of the shot-peened material, the maximum residual stress as shot-peened with SP-930 was about -1250MPa for 0.4%C specimens or about -1400MPa for 0.6%C specimens, which were almost equivalent to 0.4%C ones in 0.2% proof stress. The results could not be explained with the 0.2% proof stress before shot-peening. For 453K TEMPER and SUB-ZERO specimens, which greatly changed in retained austenite content, the sub-zero treated ones had harder surfaces before shot-peening but both showed almost equivalent values of maximum residual stress of about -1600Mpa.

As regards influences of shot-peening conditions, no significant difference in the maximum compressive residual stress was made between SP-700 and SP-930 for 0.2%C, 0.4%C and 573K TEMPER specimens. For 453K TEMPER, SUB-ZERO, QUENCH and 0.8%C specimens, however, the maximum compressive residual stress was higher with SP-930. This is probably because 453K TEMPER, SUB-ZERO, QUENCH and 0.8%C specimens became harder than SP-700 media and caused them to be plastically deformed to reduce their ability to plastically deform the specimens.[4) to 6)]

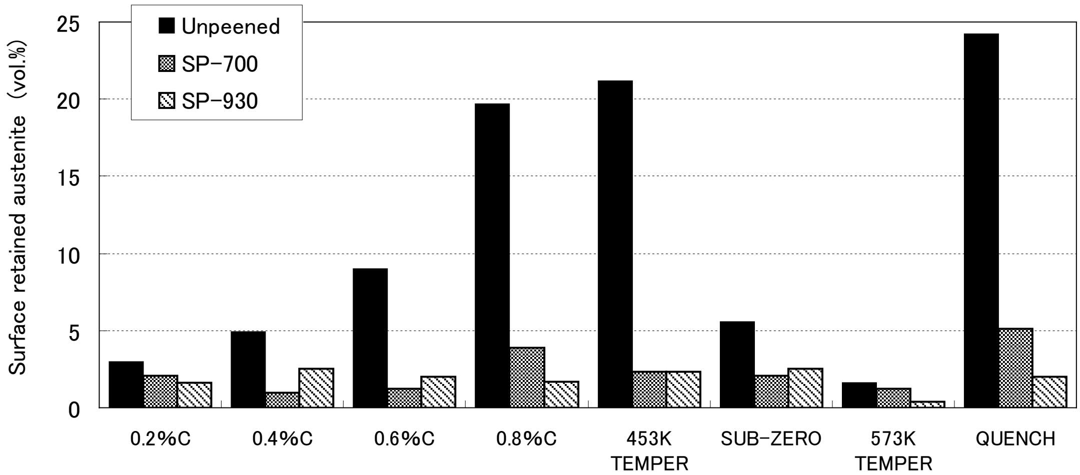

Fig.3 Surface retained austenite content

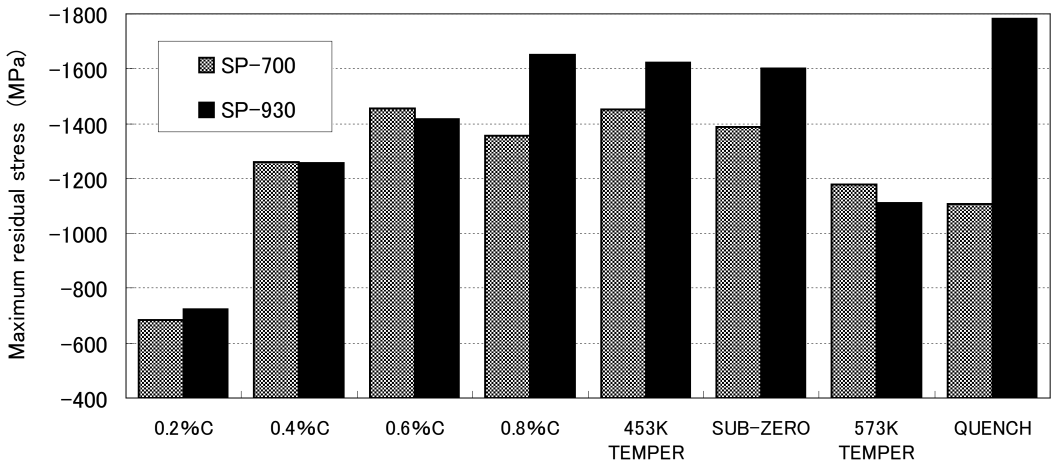

Fig. 4 Maximum residual stress

4 Considerations

4.1 Hardening effect of shot-peening

Fig.5 shows the relationship between the amount hardness increases (hardening volume) and the change in retained austenite content.

A higher change in retained austenite content led to a larger hardening volume. This is probably due to increased deformation-induced martensite in the retained austenite. This leads us to believe that the sub-zero treated specimens obtained the highest surface hardness values because of a larger amount of deformation-induced martensite and the superimposed effect of work hardening.

In addition, there was a difference in specimen hardening volume by about HV100 between SP-930 and SP-700 as shown in Figure 4. This is likely due to the difference in work hardening by shot-peening.

4.2 Residual stress application by shot-peening

Fig.6 shows the maximum compressive residual stress/0.2% proof stress as a function of the rate of change of retained austenite content.

When there was almost no change in retained austenite content, the maximum compressive residual stress applied by shot-peening was about 60% of the 0.2% proof stress of the material before shot-peening. As the rate of change of retained austenite content increased, however, the maximum compressive residual stress exceeded 60% of the 0.2% proof stress. This excessive residual stress application resulted from the compressive residual stress induced by the deformation-induced martensite in the material and probably from an increase in 0.2% proof stress caused by the hardening effect of the shot-peening process.

Then, the 0.2% proof stress was estimated from the shot-peened surface hardness using formula (1)[7] to examine its relationship with the maximum compressive residual stress and determine the hardening effect of the shot-peening process.

Fig.7 shows results of these calculations. The compressive residual stress applied by shot-peening was saturated at about 60% of the 0.2% proof stress of the shot-peened material.

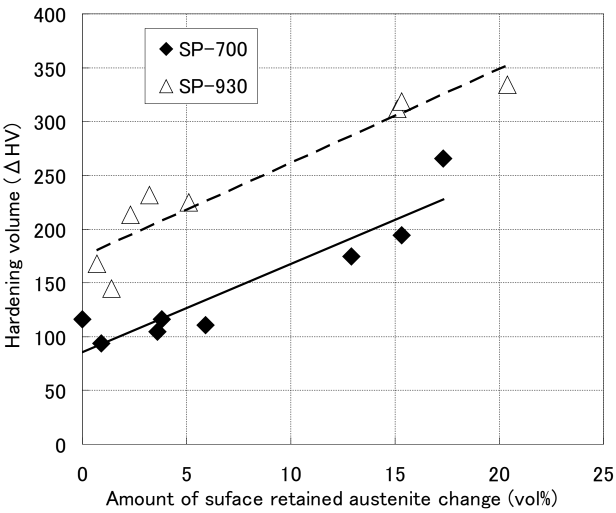

Fig. 5 Retained austenite change vs. Hardening volume

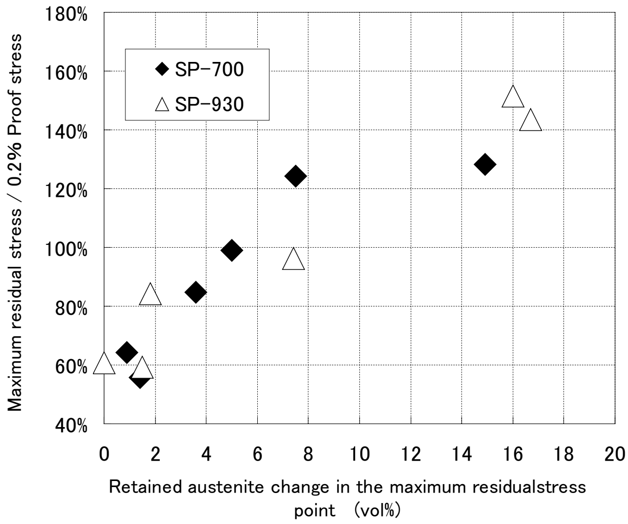

Fig.6 Retained austenite change vs. Maximum residual stree/0.2% Proof stress

$$\sigma_y = \left(\frac{HV}{\quad}\right) \times 9.80665 \times 0.95 = 3.105 \times HV \cdots (1)$$

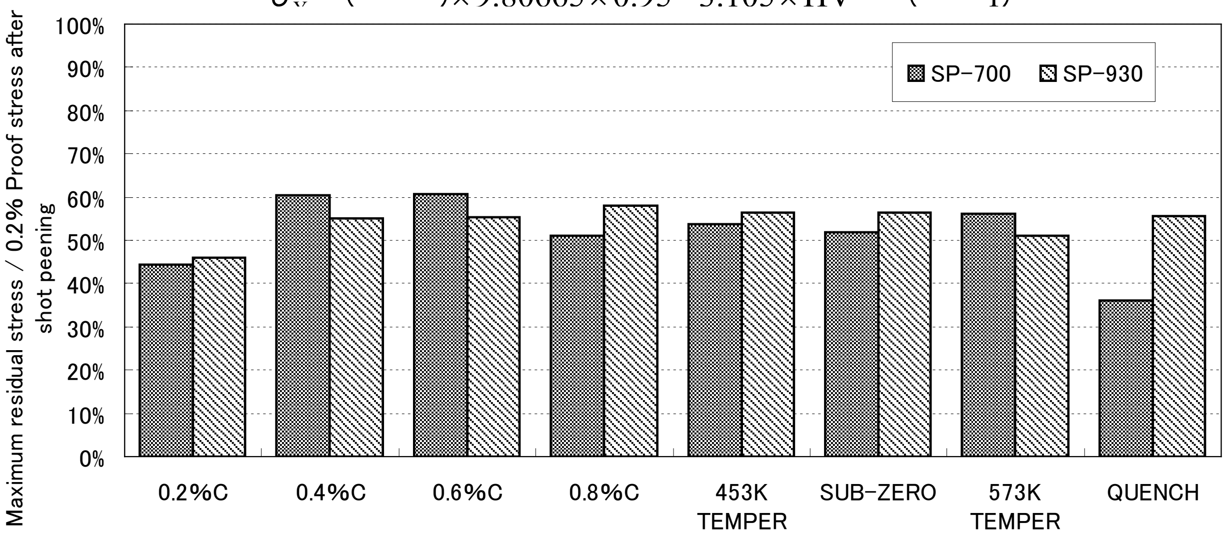

Fig. 7 Maximum residual stress/0.2% proof stress after shot peening

5 Conclusions

1. It was found that materials with a higher rate of change of retained austenite content are more easily hardened by shot-peening because of a larger amount of deformation-induced martensite and work hardening.

2. When there was almost no change in retained austenite content, the maximum compressive residual stress was about 60% of the 0.2% proof stress. A higher rate of change of retained austenite content tended to result in increased maximum compressive residual stress compared to the 0.2% proof stress. This is probably due to the increased 0.2% proof stress of the shot-peened material.

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