EFFECT OF VARIOUS PEENING PARAMETERS ON COMPRESSIVE RESIDUAL STRESS FOR CARBURIZED STEEL

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Abstract

A Design of an experiment method has clarified the contribution ratio of various peening parameters on compressive residual stress for carburized steel by using a nozzle type machine.

Various peening parameters consist of shot flow rate(15, 20, 27kg/min), exposure time (1, 5, 10sec), the distance between the tip of a nozzle and the work surface (100, 130, 180mm), shot diameter (0.6, 0.8) and shot hardness (HRC 53, 58).

The results were: (1)Exposure time and shot hardness have sensitive influence on compressive residual stress. (2)Shot flow rate, distance between the tip of a nozzle and the work surface and shot size were not so significant.

These results have suggested the idea to get the most efficient peening effect.

Key words

a design of an experiment method, peening parameters, peening effect, nozzle type machine, carburized steel

Introduction

It is well known that application of shot peening treatment to carburized gears improved the tooth bending fatigue life and pitting resistance.

To obtain high productivity of peening treatment, it is important to effectively transmit projection energy of shots to the work surface. Peening machines are roughly segmented into a wheel type and a nozzle type, both of which have their own merits. We investigated how various parameters contribute to the efficiency of energy transmission by the design of an experiment method with a nozzle type peening machine. Experimental conditions of parameters set in this study are within the range of practical peening treatment.

Experimental procedure

Specimens.

Table 1 shows the chemical composition of material used. The material is ordinary steel used for mission gears of automobiles. Fig.1 shows the shape of specimens. The specimens were tempered at 160 ℃ after conventional gas carburizing. Effective case depth was 1.0 mm; surface hardness was 61 in Rockwell hardness.

Table 1 : Chemical composition (Weight percentage)

JIS SCM420	C	Si	Mn	P	S	Cr	Mo
	0.20	0.28	0.71	0.02	0.02	1.12	0.26

Peening conditions.

The study by the design of an experiment method consist of 2types.

In the first experiment, using shots of HRC 53 and 0.8mmϕ, effect of the shot flow rate, the distance between the tip of a nozzle and the work surface and exposure time on compressive residual stress were studied. Table 2 shows the assignment of experimental conditions.

Table 2 : Design of the first experiment

Factor \ Level	1	2	3
Shot flow rate (kg/min)	15	20	27
Distance between a nozzle and the work surface (mm)	100	130	180
Exposure time (sec)	1	5	10

In the second experiment, fixing the shot flow rate and the distance between the tip of a nozzle and the work surface, the effects of shot size and hardness on compressive residual stress were studied. Table 3 shows the assignment of experimental conditions.

In both experiments, the specimens were fixed and peened at air pressure of 5.5kgf/cm^2.

Table 3 : Design of the second experiment

Factor \ Level	1	2
Shot size (mmϕ)	0.6	0.8
shot hardness (HRC)	53	58
Exposure time (sec)	1	5

Measurement of compressive residual stress.

Compressive residual stress was measured by X-ray diffraction. Irradiation range was narrowed for measurement to 8mm in diameter by masking. Measurement was made for the direction of depth by electric polishing.

X ray : Cr $K\alpha$ radiation
Diffraction plane : (211)
Measurement mode : $\sin^2\psi$-2θ
Young's modulus : 21000 kgf/mm^2
Poisson ratio : 0.28
ψ_0 angle : 0, 15, 30, 45°

The direction of measurement were both X and Y directions and both showed no significant difference by shape; accordingly, the average of both values were used as measurement values.

Experimental results

Influence of the shot flow rate, the distance between the tip of a nozzle and the work surface and exposure time (1st experiment).

27 stress curves were analyzed by the design of an experiment method.

Fig.2 shows the distribution of compressive residual stress at various values of exposure time. The maximum value of compressive residual stress was found at the depth of 60 ~70μm from the surface. The difference in exposure time significantly affected the curve of compressive residual stress.

Fig.3 shows the contribution ratio of the shot flow rate, the distance between the tip of a nozzle and the work surface and exposure time on compressive residual stress obtained by analysis of variance. From a hypothesis test, exposure time and the distance between the tip of a nozzle and the work surface became significant when a significance level was 5%. From these results, under such conditions, the contribution of exposure time was the largest, that of the distance between the tip of a nozzle and the work surface was next and the shot flow rate did not contribute much.

Fig.4 shows the relation between the distance between the tip of a nozzle and the work surface and the maximum compressive residual stress value at various shot flow rate. Exposure time is consistently 10 sec. When the distance is longer, compressive residual stress is smaller; this may be due to a decrease in shot speed when shots arrived at the work surface. The effect of shot flow rate on compressive residual stress did not show any clear difference. The same results were obtained in other exposure time also.

Fig.5 shows the relation between exposure time and the maximum compressive residual stress value at various distances between the tip of a nozzle and the work surface. Shot flow rate is consistently 15kg/min. The result shows that a peening effect is sensitive to the change of time. This was the same for other shot flow rate.

Influence of shot hardness and shot size (2nd experiment)

From the result in Fig 3, exposure time is the most influencial factor when the properties of shots are constant. In the following experiment, the effects of shot hardness and shot size to compressive residual stress were studied. These properties were compared with the exposure time. Experimental conditions were as shown in Table 3.

Fig.6 shows the contribution ratio of shot hardness, shot size and exposure time on compressive residual stress obtained by analysis of variance. From a hypothesis test, shot hardness, exposure time and the interaction between shot hardness and shot size became significant when a significance level was 1%. Contribution of shot size is not so significant, so it was pooled to error.

Fig.7 shows the relation between shot hardness and the maximum compressive residual stress value at various shot size. Shot hardness remarkably influences compressive residual stress.

As another important result, shots of HRC 53 and 0.8 mm ϕ showed higher values of compressive residual stress than those of HRC 53 and 0.6 mmϕ. On the other hand, shots of HRC58 showed a reversed result. These observations show that shot hardness and shot size are interacted.

Discussion

Kinetic energy of a shot to transmit to the steel surface is expressed in Equation①.

$$e = (1/2)mv^2 \sin\theta \qquad ①$$

where m : Mass of a shot
v : Shot speed
θ : Impact angle

Kinetic energy of shots to transmit in time T is expressed in Equation②.

$$E_T = \left[(1/2)mv^2 \sin\theta \right] \cdot N \cdot S \cdot T \qquad ②$$

where N : No. of shots hitting against unit time and unit area
S : Projection area

However, energy loss by mutual interference of shots on the work surface and a shot rebound is considered to be actually a large factor. providing the energy transmitting efficiency of these effects is K, ② is changed to ③.

$$E_T = \left[(1/2)mv^2 \sin\theta \right] N \cdot S \cdot T \cdot K \qquad ③$$

The energy generates heat by internal friction and compressive residual stress as strain energy on the steel surface. The rate of energy converted to both heat and compressive residual stress is considered to change with exposure time. The level of compressive residual stress stored as strain energy depends on the mechanical property of a work piece, shape dependence (particularly thickness) is also reported.

The result of the first experiment showed that time T is the most important factor and sensitive to a peening effect. Namely, in order to obtain target stress, the most important control factor is time. It is also significant that time is directly related to productivity of peening treatment.

Change of shot flow rate did not show any significant effect at the range of condition of this study. It is considered that shot flow rate is related to N and K on Equation ③ and this result suggest that exess projection causes mutual interference of shots on the work surface. Too much projection causes severe wear by mutual interference of shots.

A notable result in the second experiment is that the contribution of shot hardness is ten times of that of time. Since an increase in shot hardness decreases energy loss by deformation of a shot itself at collision, the efficiency of transmission is considered to be increased. In practical operation, attention must be paid that shot wear and shot hardness are related each other.

The cause of interaction between shot hardness and size is discussed. Providing average stress generated between the shot and work surface of contact at the moment of collision is σ, equation ④ is formed.

$$\sigma = \varepsilon \cdot E \qquad ④$$

Where ε : Shot strain

E : Young's modulus of shot

σ is related to momentum before collision. Momentum is increased in proportion to (shot size)^3, Shot size contributes to σ by cube; accordingly, it is considered that shot strain is strongly related to the shot size from the Equation ④.
For soft shots, the contribution of the difference of $1/2mv^2 \sin\theta$ due to mass difference is larger than that of energy loss due to shot deformation and increase the transmission efficiency of shot of 0.8 mm ϕ. For hard shots, on the other hand, it is concidered that change in energy loss due to hard-dependent deformation denies the contribution of mass difference and decreases the transmission efficiency of 0.8 mm ϕ shots than that of 0.6 mmϕ.

Conclusion

In shot peening treatment for carburized steel, the contribution ratio of various peening parameters (shot flow rate, the distence between the tip of a nozzle and the work surface, exposure time, shot size, and shot hardness) on compressive residual stress is the following order under the conditions in the study.
Shot hardness > exposure time > the distance between the tip of a nozzle and the work surface, shot flow rate, shot size.

References

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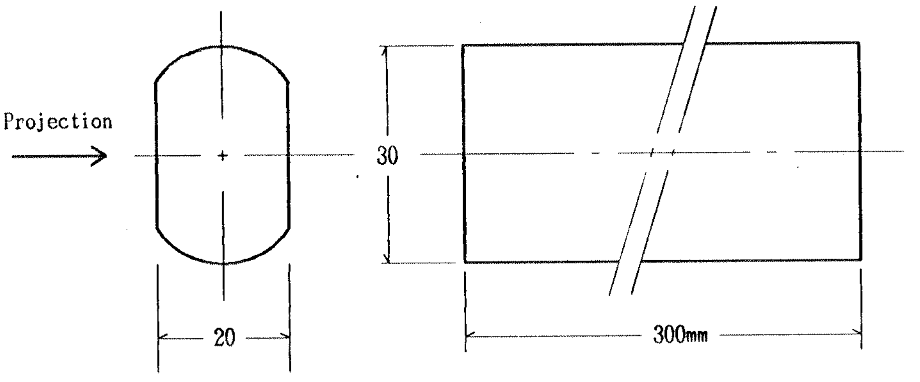

Fig 1. Shape of specimen

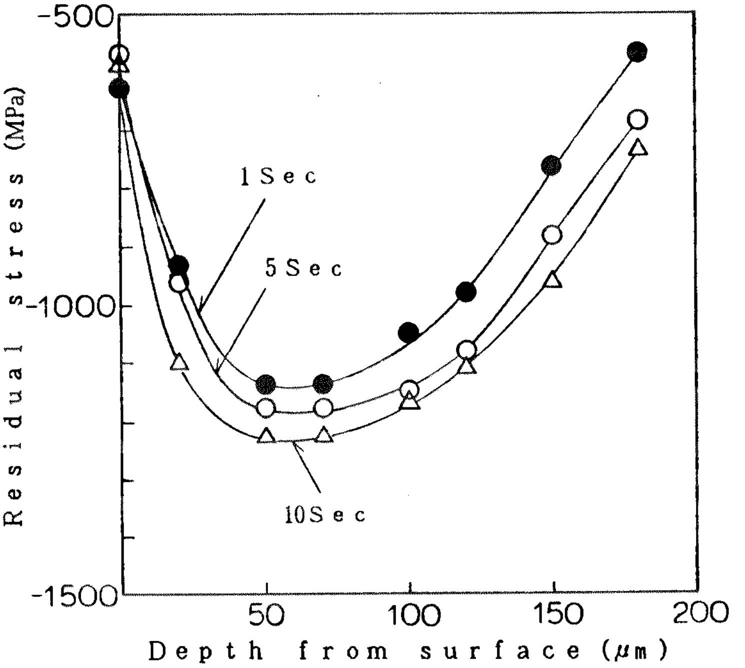

Fig. 2 Distribution of compressive residual stress

Shot flow rate : 15 Kg/min

Distance between the tip of a nozzle and the work surface : 130mm

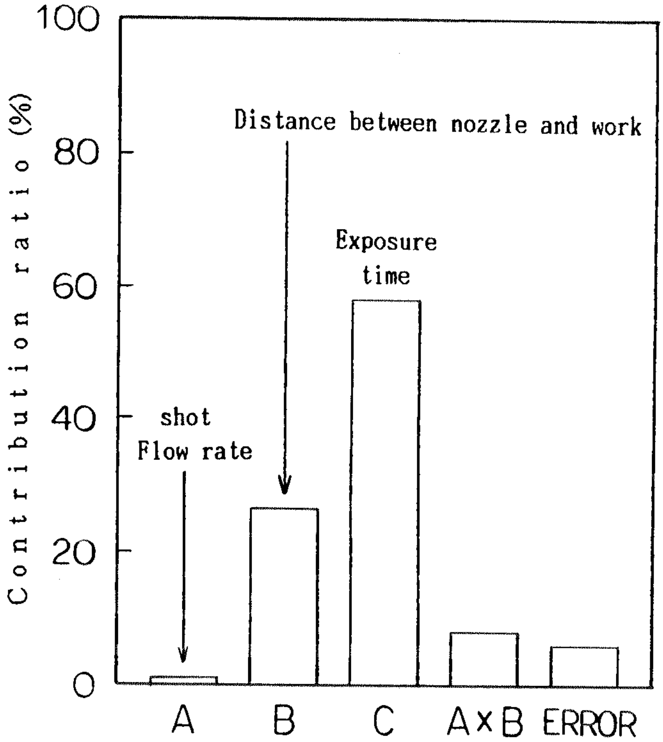

Fig.3 Result of analysis of variance
(1st experiment)

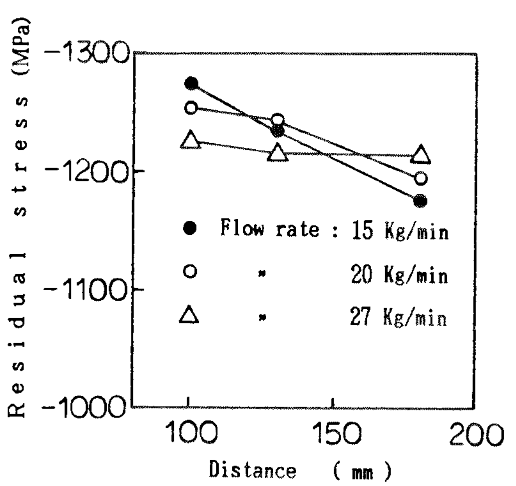

Fig.4 Relation between distance (nozzle and work)
and residual stress
Exposure time : 10 sec

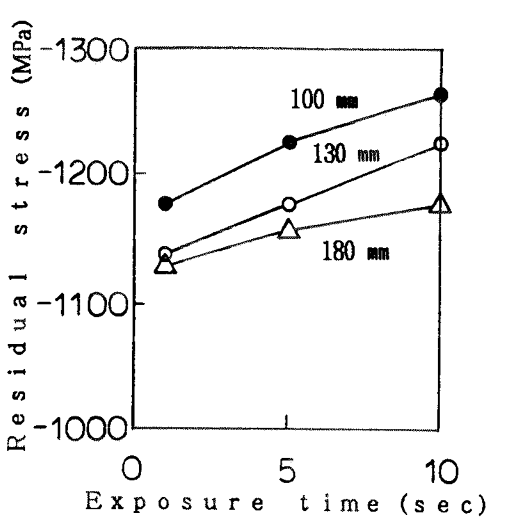

Fig.5 Relation between exposure time
and residual stress
Shot flow rate : 15Kg/min

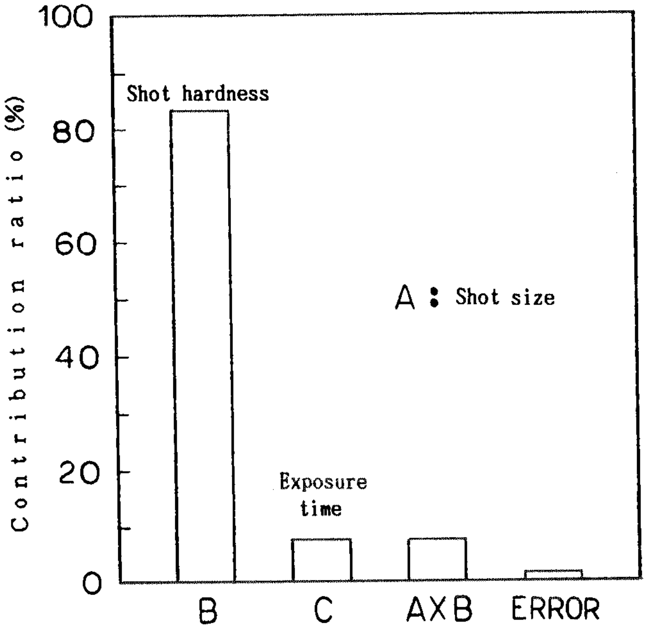

Fig.6 Result of analysis of variance
(2nd experiment)

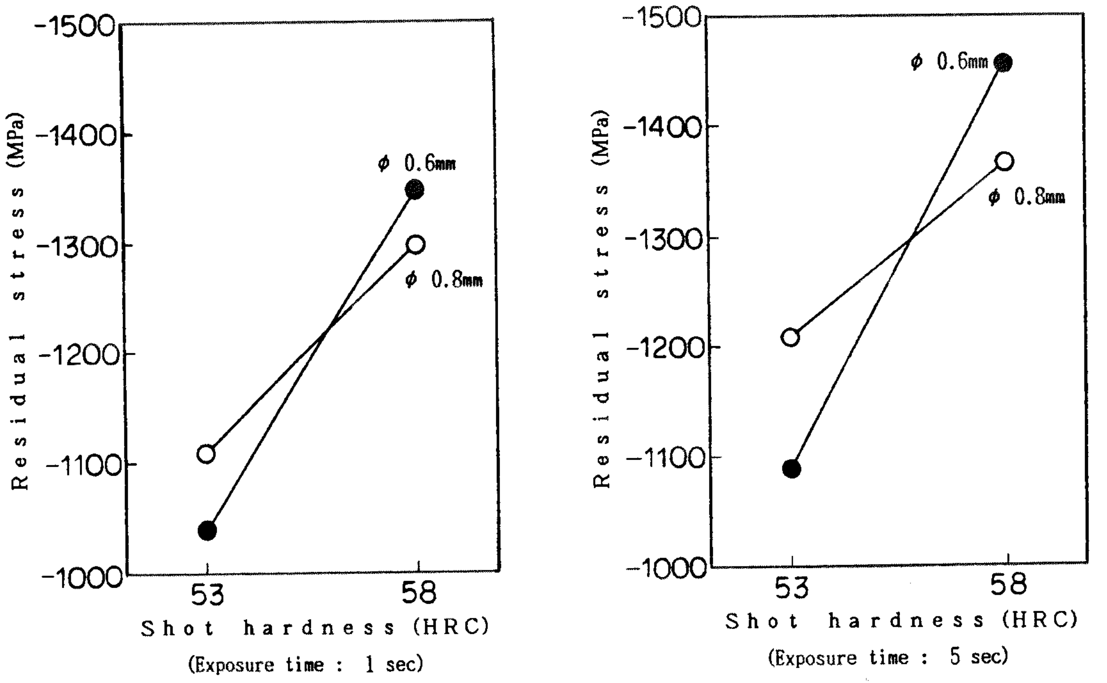

Fig. 7 Relation between shot hardness and residual stress