THE EFFECT OF SHOT-PEENING TO DECARBURIZED SPRING STEEL PLATE

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ABSTRACT

The aim of this paper is to present experimental results about the relation between the decarburization and the effect of shot-peening, and also to propose the appropriate shot-peening condition for the decarburized SUP6(Si-Mn steel) spring steel plate. In the fatigue tests, it was realized that the larger the depth of the decarburized layer,DM-T,became,the less the fatigue life did.

It was also found that the fatigue life can greatly increase by means of applying shot-peening twice by different shots under the following conditions.

1) 0.7mm steel-shot → 0.4mm cut-wire
2) 0.7mm steel-shot → glass-beads(wet-honing)

However,even in these shot-peening conditions,it was noted that there were no difference of the fatigue life in the conventional shot-peening condition when the DM-T was over 0.15mm. These experimental results were also discussed, taking the surface roughness,hardness(work-hardening),and residual stress distributions of the specimens into consideration.

KEYWORDS

Decarburization; fatigue life; surface roughness; work-hardening; residual stress

INTRODUCTION

In the processes of manufacturing automotive suspension spring,shot-peening is one of the most essential processes for improving its fatigue life. Since the materials of spring are produced by hot-rolling, it would not be possible to obtain the materials which have no decarburization at all. The hardness around the decarburized layer is lower than the others,and the residual stress of tension is said to exist around there,(1). Although the decarburized layer of which the depth is ranged from 0.05mm to 0.10mm,can reduce the fatigue strength of spring to more than the one-half of the polished materials,(2) and(3), shot-peening can overcome the decarburized spring to improve its fatigue life,(4)and(5). However,while the art of shot-peening has been well developed, the sufficient works for the effect of shot-peening to the decarburized material would not be made as yet.

In the present works, experimental results for the fatigue test in several decarburized conditions were given,and the effect of shot-peening to these decarburized leaf spring was studied. The appropriate shot-peening method for improving the fatigue life further was also proposed. Experimental results were discussed,taking the surface roughness,work-hardening and residual stress distributions of the specimens into consideration.

EXPERIMENTAL PROCEDURES

1. Materials

The materials employed here are the SUP6(Si-Mn steel) hot-rolled spring plate of which size is 8mm(0.008m) in thickness,70mm(0.07m) in width, and 550mm(0.55m) in length. TABLE 1 shows the chemical composition of the material. The five decarburized specimens are selected, as shown in TABLE 2. The specimen 1 in the TABLE2 is the polished material,as it is not possible to obtain perfectly non-decarburized specimen. The specimen 5 is the most decarburized specimen by intentionally heat-treating in electric furnace. The depth of the decarburized layer,say DM-T,was measured initially by decarburized depth measuring device with eddy current,and after fatigue tests the microscopical method was applied to the determination of the DM-T.

TABLE 1 Chemical composition(wt%)

	C	Si	Mn	P	S
SUP 6	0.55~0.65	1.50~1.80	0.70~1.00	<0.035	<0.035

TABLE 2 DM-T of specimens

Specimen NO.	Condition before heat-treatment	Condition of heat-treatment	DM-T after heat-treatment
1	0.3mm polished	950°C,16min. oil quenching 520°C,60min. temper,water cooling. HRC 41.8~43.1	0
2	As rolled		0.05~0.10mm
3			0.10~0.15mm
4			0.15~0.20mm
5	800°C,60min*		0.20~0.25mm

* Heat-treated in electric furnace.

2. Shot-peening condition

TABLE3 shows the shot-peening conditions applied in the present experiments, and the combinations of the shot-peening condition are also shown in TABLE4.

In the experiments which investigate the relation between the depth of the decarburized layer,DM-T, and the fatigue life, the shot-peening condition(2) in the TABLE4 was always applied. The most effective condition in the TABLE4 were also determined experimentally.

3. Fatigue test condition

The fatigue tests were carried out in the bending stress condition of pulsating repeated stress. The mean stress was 65Kgf/mm^2 (637.4 MPa) and stress amplitude was ± 40 Kgf/mm^2 (392.3 MPa).

Before the fatigue tests the setting stress 120 Kgf/mm^2 (1176.8 MPa) was applied to the specimens. These stress values were measured by strain gauge.

TABLE 3 Shot-peening conditions

Condition	Shot-size	flow rate of shot	Wheel speed	Conveyor speed
A	0.4mm cut-wire	95Kg/min.	56.4m/sec.	3m/min.
B	0.7mm steel-shot	87Kg/min.	51.3m/sec.	
C	0.2~0.3mm glass-beads	0.5 *1)	0.49 MPa *2)	15min. *3)

*1) The ratio of glassbeads to water
*2) Injection pressure
*3) Exposure time

TABLE 4 Combinations of shot-peening conditions

Condition NO.	Combination of shot peening	Intensity (Arc height)	Coverage
(1)	A 1pass	0.25mmA	>95%
(2)	B 1pass	0.39mmA	>95%
(3)	B 3pass	0.44mmA	>95%
(4)	B 5pass	0.46mmA	>95%
(5)	B 1pass + A 1pass	0.40mmA	>95%
(6)	B 1pass + C	0.46mmA	>95%

4. Residual stress measurement

The residual stress caused by shot-peening was measured by X-ray diffraction. The locations of residual stress measurement were in the distance of 20~30mm from the fracture area, avoiding the influence of the fatigue fracture to the stress values. The residual stress distributions were also obtained. The stress measurements were carried out by partially electro-polishing to the measuring area of the specimen. Each residual stress value obtained by X-ray diffraction was corrected ,taking the effect of eliminated layer into account.

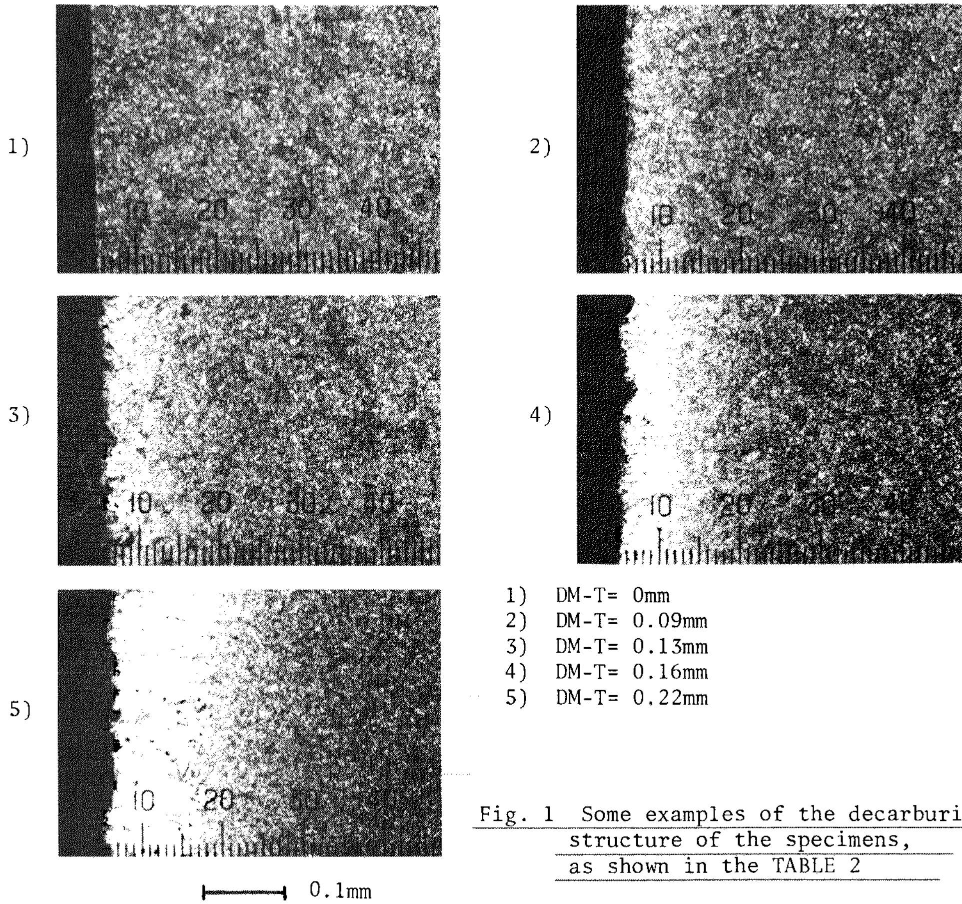
RESULTS AND DISCUSSIONS

1. The relation between the depth of the decarburized layer, DM-T, and the fatigue life of the specimen.

The decarburized conditions of the specimens in the TABLE2 are shown in Fig.1, as the decarburized structure.

The each number of fatigue test specimen is three, and the shot-peening condition employed here is the condition(2) in the TABLE4. The results of the fatigue tests are shown in Fig.2. It can be seen from the Fig.2,that the fatigue life can be greatly affected by the depth of the decarburized layer,DM-T.

The fatigue life can decrease proportionally,as the DM-T becomes greater.It is also noted from the Fig.2,that the fatigue life of the specimen of which the DM-T is 0.19mm, becomes one-half of that of non-decarburized specimen.



1) DM-T= 0mm
2) DM-T= 0.09mm
3) DM-T= 0.13mm
4) DM-T= 0.16mm
5) DM-T= 0.22mm

Fig. 1 Some examples of the decarburized structure of the specimens, as shown in the TABLE 2

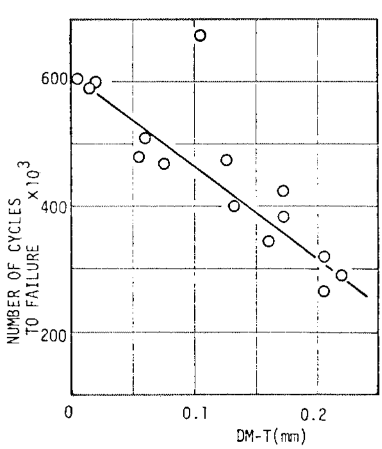


Fig. 2 The relations between the DM-T and fatigue life

2. Improvement of fatigue life

In order to determine the most appropriate shot-peening condition for improving the fatigue life of the decarburized specimen,the fatigue lifes in the six shot-peening conditions shown in the TABLE 4 are compared.

The specimens employed here,therefore,have the similar condition of decarburization of which the depth are ranged from 0.11mm to 0.13mm.

The results are shown in Fig.3. It can be found that the fatigue life is much improved when shot-peened in the condition (5)and(6). This means that applying shot-peening twice by different shots,first by 0.7mm steel-shot,say 0.7ss, and secondly by 0.4mm cut-wire,say 0.4cw, or glass-beads(wet-honing) is the most effctive shot-peening condition.

Since there appear to be little difference of the fatigue life among the condition (1),(2),(3),and(4), it can be concluded that shot size itself,and the number of pass by the same shot have little correlation with improving the fatigue life of the decarburized materials. The relations between these experimental results and the surface roughness,hardness,and residual stress distributions are discussed as follows.

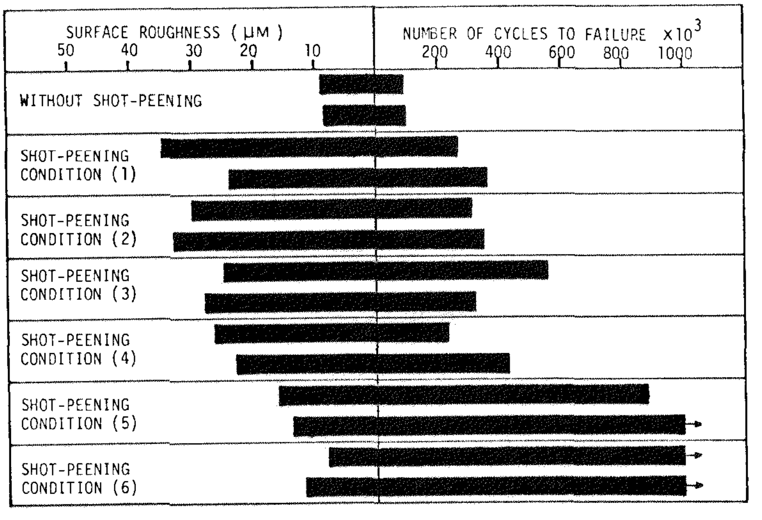


Fig. 3 Fatigue life(number of cycles to failure) and surface roughness in several shot-peening conditions shown in the TABLE 4. The DM-T of specimens are ranged from 0.11mm to 0.13mm.

(1) Surface roughness

The Fig. 3 also indicates the relations between the surface roughness and fatigue life. It can be seen from the Fig.3, that the surface roughness of specimen is greatly responsible for the fatigue life. The smaller the surface roughness is, the greater the fatigue life becomes.

(2) Hardness

The hardness of specimen in each shot-peening condition is shown in Fig.4. The locations of measurement are in the distance of 0.05mm from the surface.

Since the area where the hardnesses were measured,are decarburized, the values of hardness are much lower than the other area of specimens. The Fig.4 shows that although the decarburized layer can be somewhat work-hardened, there appear to be little correlation between the hardness and the fatigue life.

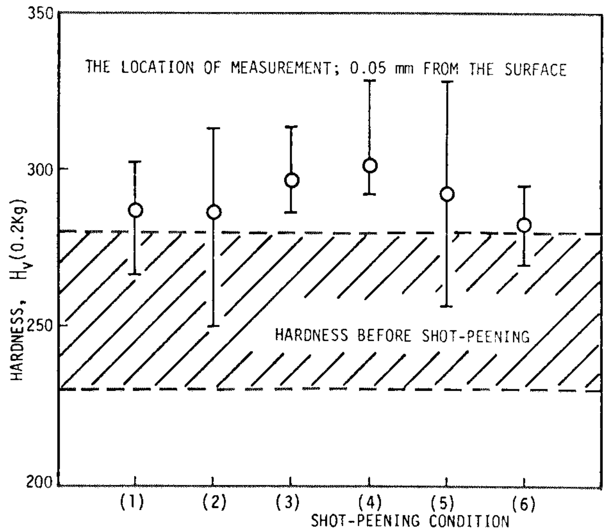


Fig. 4 Hardnesses before and after shot-peening in several shot-peening conditions shown in the TABLE 4.

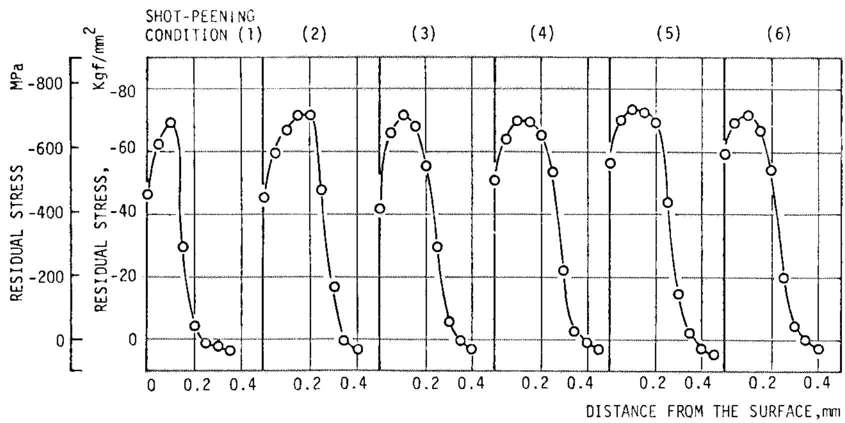


Fig. 5 Residual stress distributions in several shot-peening conditions shown in the TABLE 4.

(3) Residual stress distribution

The residual stress distribution in each shot-peening condition is shown in Fig.5. It is realized that there would be no remarkable diffence of both the location and value of the peak(maximum compressive residual stress) among these shot-peening conditions. However, in the stress distributions of the shot-peening condition (5)and(6), which were very effective for improving the fatigue life, the residual stress values between the surface and the 0.1mm depth seem to be somewhat greater than the others.

This may be the reason why the condition (5)and(6) is more effective for improving the fatigue life , but the main reason could be the diffence of the surface roughness,see the Fig.3.

3. The limit of improving the fatigue life

It was found in the former section that the fatigue life of the decarburized specimen of which the DM-T was ranged from 0.11mm to o.13mm can be greatly improved by applying shot-peening twice by different shots,in the condition of first 0.7ss and secondly 0.4cw. In this section, fatigue test is extended to the specimens which have further greater DM-T, and the limit of the DM-T for improving the fatigue life by this shot-peening condition(0.7ss→0.4cw) is investigated.

The relations between the fatigue life and the DM-T are shown in Fig.6. Two shot-peening conditions are employed. The symbol ○ represent the experimental results shown in the Fig.2. This shot-peening condition is the (2) in the TABLE4 (0.7ss). The symbol ● means the fatigue life when applying the condition (5).

It can be seen from the Fig.6, that when the DM-T of the specimens are less than 0.15mm, the fatigue life are greatly improved by the condition(5). However, it can be also recognized that even the condition(5) cannot be effective when the DM-T becoming over 0.15mm.

Therefore, it would be concluded that the DM-T value of 0.15mm,is the limit of improving the fatigue life of the decarburized spring steel.

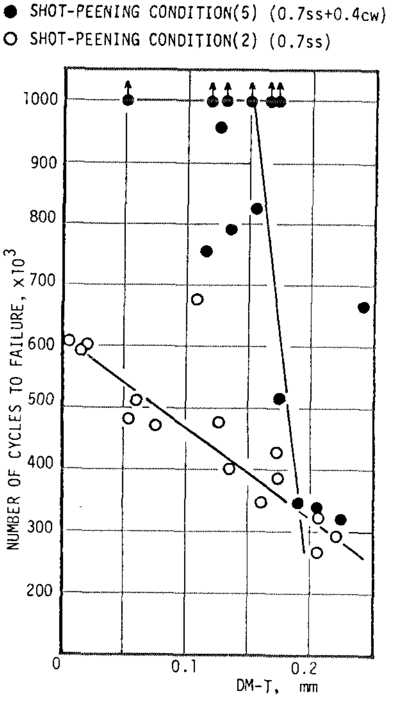


Fig. 6 The relations between the DM-T and fatigue life (condition (2)and(5))

The results shown in the Fig.6,can be discussed,again taking the surface roughness, hardness,and residual stress distributions into consideration.

(1) Surface roughness

Fig.7 shows the relations between the DM-T and surface roughness of the specimens shown in the Fig.6. The symbol ● in the Fig.7 indicates the specimen of which the DM-T is over 0.15mm. This means that the symbol ● is over the limit of improvement of fatigue life by the shot-peening condition(5). It can be noted from the Fig.7, that there are good correlations between the DM-T and surface roughness,and as the DM-T becomes greater the surface roughness does greater.

Fig.8 also shows the relations between the surface roughness and fatigue life. It can be seen that the surface roughness is greatly responsible for the fatigue life. This can be easily explained by the stress concentration which may be caused by the rough surface condition. When the DM-T is over 0.15mm,the surface roughness appears to be over 0.028mm(28μm).

(2) Hardness

The relations between the fatigue life and hardness in the 0.05mm depth from the surface is shown in Fig.9. The trend obtained from the Fig.9 is that the fatigue life can increase as the hardness becomes greater. It can be realized that the hardnesses of the specimens of which the DM-T are over 0.15mm,are less than Hv300.

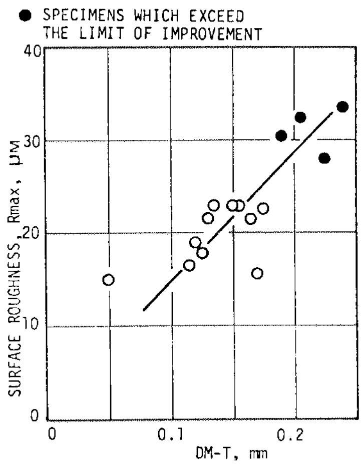


Fig. 7 The relations between the DM-T and surface roughness

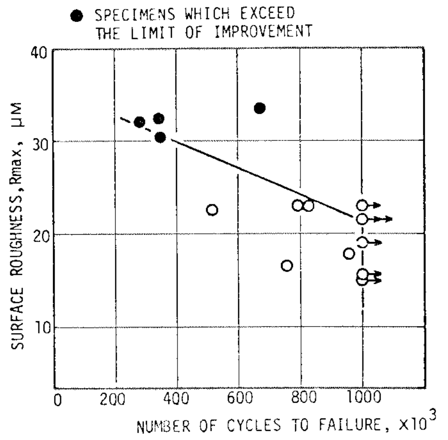


Fig. 8 The relations between the surface roughness and fatigue life

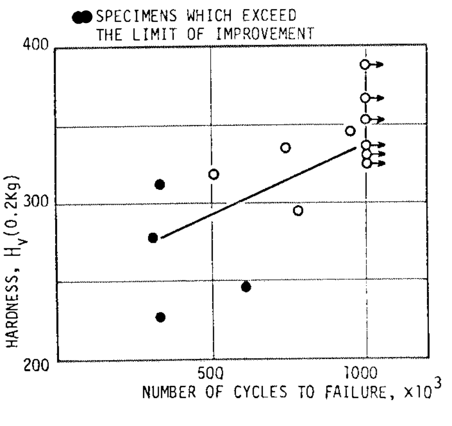


Fig. 9 The relations between the fatigue life and hardness in the 0.05mm depth from the surface.

(3) Residual stress distribution

Fig. 10 shows some examples of the residual stress distributions. As the DM-T becomes greater, both the stress value in the surface and that of the peak seem to become less,and also both the location of the peak and the crossing point(residual stress is zero.) seem to become deeper. This can be thought that because of the low hardness in the decarburized area, the decarburized layer can be plastically deformed to remain the smaller residual stress.

Fig.11 indicates the relations between the residual stress at the 0.1mm depth from the surface and the fatigue life, and also the relations between its residual stress and the DM-T are shown in Fig.12.

Both the fatigue life and the DM-T appear to have great correlation with the residual stress. It is also found from the Fig.11 and Fig.12, that the residual stress becomes smaller, as the fatigue life becomes less and the DM-T becomes greater. The residual stress of the specimens of which the DM-T are over 0.15mm,are comparatively lower and its values are less than -63Kgf/mm²(617.4 MPa).

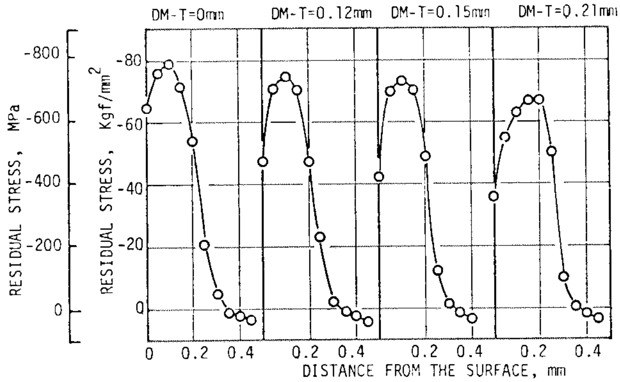


Fig. 10 Some examples of the residual stress distributions

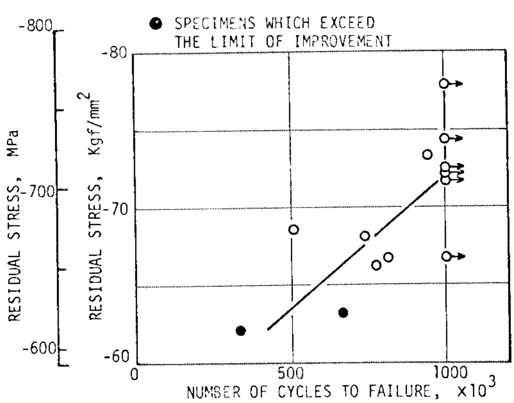


Fig. 11 The relations between the fatigue life and residual stress at the 0.01mm depth from the surface.

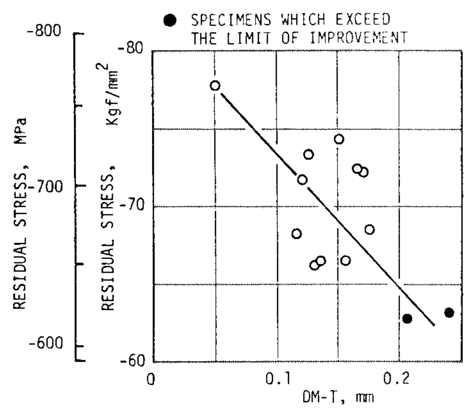


Fig. 12 The relations between the DM-T and residual stress at the 0.1mm depth from the surface.

CONCLUSION

The following experimental results for the effect of shot-peening to the decarburized spring steel are obtained.

(1) Although the conventional shot-peening can improve the fatigue life of decarburized spring steel,it is inevitable that the fatigue life of them decrease as the depth of the decarburized layer,DM-T,increases.

(2) The proposed shot-peening condition which can greatly increase the fatigue life of the decarburized spring steel is to make shot-peening twice by different shots,first by 0.7mm steel shot,and secondly by 0.4mm cut-wire or glass-beads(wet-honing).

(3) The proposed shot-peening condition can improve the surface roughness of the specimen and make the residual stress around the surface relatively greater than the conventional shot-peening. These can be eventually due to increasing the fatigue life.

(4) It is not possible for the specimens of which the DM-T are over 0.15mm,to be improved their fatigue life by the proposed shot-peening condition.

(5) The features of the specimens which cannot be improved by the proposed shot-peening condition are that their surface roughness are over 0.028mm(28μm), their hardness are under Hv 300, and their residual stresses around the surface area are under -63Kgf/mm^2(-617.4 MPa).

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