THE INFLUENCE OF BROKEN SHOTS ON PEENING EFFECT OF HARD SHOT PEENING

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ABSTRACT

Hard shot peening characterized by its larger shot injecting energy with arc height higher than 0.7 mmA is becoming popular as one of the methods to enhance the fatigue durability especially for case hardened components. During this process many shots are broken compared to conventional peening process. In this study, to clarify the influence of broken shots on fatigue properties, two types shots having two different hardness respectively are prepared. Ervine tests reveals that one of them has many broken particles and another has a little. Using these two types shots specimens were hardly peened and fatigue tests are carried out to obtain S-N curve and weibull charts. The specimens peened with shots containing many broken shots show wider distribution of fatigue life than the ones peened with shots containing of a little. It is concluded that broken shots degrade the stability of peening effect in hard shot peening.

KEYWORDS

Hard shot peening, Carburized steel, Residual stress, Retained austenite, Fatigue test, S-N curve, Weibull chart

1. INTRODUCTION

Many of the power train components have been strongly demanded to withstand higher loads with increasing engine power and with the trend in down sizing. It is especially desired for automotive transmission gears to transmit increased engine out put. To meet these requirements, high performance gear steels have been developed based on the studies on gear manufacturing process, heat treatment and designs. Shot peening of carburized gears is becoming popular as one of the methods to enhance the fatigue durability, and its effects have been already reported [1]-[3]. Furthermore, hard shot peening with arc height higher than 0.7mmA is also applied. By this hard peening process, it is indicated that it leads to an increase in 25% to 30% of fatigue strength compared to conventional peening [4]-[5]. It is suggested, on the other hand, that fatigue properties of shot peening gears show larger scattering than those of as carburized - tempered gears, because it is difficult to control the shot peening parameters precisely such as shot hardness, shot diameter, injection velocity and so forth. During hard shot peening process, a large amount of shots are broken by high energy bombardment. And these broken shots are indicated not only to reduce peening effects but to degrade the stability of peening effects.

In this study, to clarify the influence of broken shots on fatigue properties, two types of shots having two different hardness Hv550 and Hv700, respectively are prepared. By Ervine tester, they exhibit the different amount of broken shots in both hardness level. Using these two types shots, carburized specimens are hardly peened with same arc height, and the distribution of hardness, residual stress and retained austenite content are measured to confirm the shot peening effect. Fatigue tests, furthermore, are carried out to obtain the S-N curve and Weibull charts for discussion.

2. EXPERIMENTAL PROCEDURES

2.1 Material, heat treatment and dimensions of specimens

Case hardened Cr-Mo Steel (JIS SCM420) with the chemical composition given in Table 1 was used for the round bar type rotating bending fatigue test. The geometries of specimens were shown in Fig. 1. After annealing for 1 hour at 920°C and machining, specimens were carburized according to the condition shown in Fig. 2. Carburizing has been carried out for 3 hours at 910°C. After cooling to 830°C and holding for 0.5 hour at this temperature, specimens were quenched in oil of 80°C. Tempering was carried out for 2 hours at 160°C. This heat treatment resulted in a surface carbon content of 0.93 %. After shot peening, the grip of specimens were finish machined to the diameter of 15mm by grinding.

Table 1 Chemical composition (wt %)

C	Si	Mn	P	S	Cu	Ni	Cr	Mo	S-Al
0.20	0.26	0.84	0.018	0.013	0.09	0.08	1.19	0.15	0.021

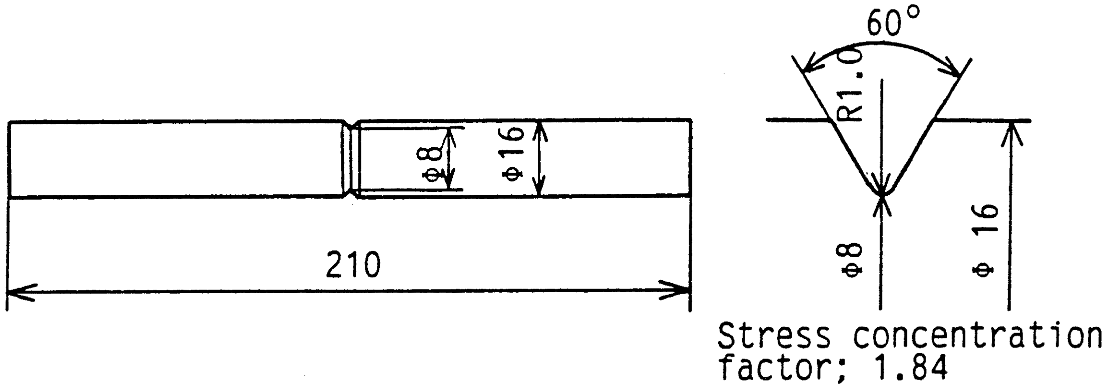

Fig. 1 The geometries of specimens

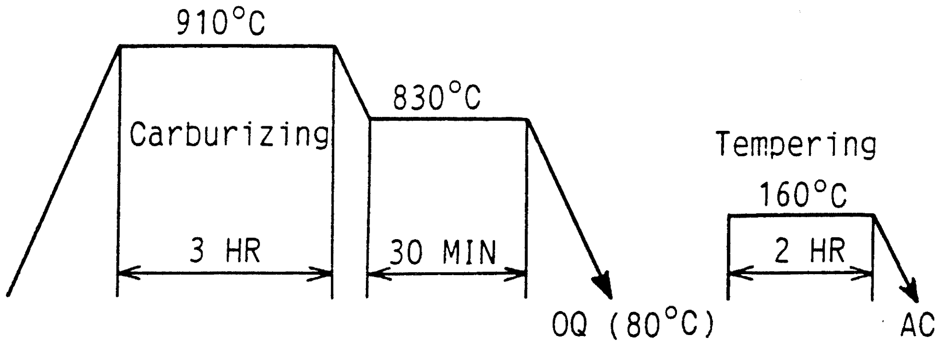

Fig. 2 The condition of Carburizing

2.2 Shot peening treatment

2.2.1 Shot media To clarify the influence of broken shots that crashed during peening process on fatigue properties, two types 0.8mm dia. shots having two different hardness Hv 550 and Hv 700, respectively are prepared. By Ervine tester, shots were gradually broken to smaller one. So after cyclic injection the broken particles under 710 μm were removed and the amount of retained wieght were measured . Table 2 shows these shot media and the results of retained wieght %. At the shot hardness of Hv 550, the amount of retained shot of A-group was 93.55% and B-group was 80.90%. At the hardness level of Hv 700, on the other hand, retained particles of B group shot remarkably decreased to 7.80%, whereas A group showed 83.90%. As results of Ervine test, A group shot has less broken shots during peening process than B group in both hardness level.

2.2.2 Shot peening machine and peening conditions Shot peening was carried out by wheel type peening machine using the shot media as mentioned above. The shot velocity was 106 m/sec. The specimens set perpendicular to the streaming direction at 300 mm distant from the wheel were rotated at 12 rpm. Broken shots under 710 μm were removed by sieving machine of 300 Kg/min in capacity. The peening condition was decided to obtain the Almen intensity 0.7 mmA for shot hardness of Hv 550 and 1.0 mmA for Hv 700. They were shown in Table 3. It is seemed that the reason for short peening time of B-group compared to A-group is different in mean diameter between A and B shot shown in Table 2.

Table 2 Shot media and the results of retained weight

Hardness level	Group	mean hardness (Hv)	mean diameter (mm)	Retained weight (wt %)
Hv 550	A - 1	594	0.852	93.55
	B - 1	576	0.922	80.90
Hv 700	A - 2	678	0.859	80.90
	B - 2	692	0.925	7.80

Table 3 Shot peening condition

Group	Peening Time (min)	Arc Height (mmA)
A - 1	5	0.70
B - 1	3	0.70
A - 2	10	1.00
B - 2	3	1.02

2.3 Peening effects

In order to confirm the peening effects, the distribution of hardness and residual stresses near the surface and retained austenite were measured. The Vicker's hardness distribution was measured from the surface to depth of 2 mm by loading 300 gf for 15 sec. The residual stresses were determined by X-ray diffractometer with the $\sin^2\psi$ - method. The residual stress distribution was obtained by repeating the X-ray measurement and electrochemical polishing successively. The amount of retained austenite was also determined by means of the X-ray diffractometer. The retained austenite content was calculated after measuring diffraction line intensities of the (211)-planes of martensite and the (220)-planes of the austenite with chromium $k\alpha$ - radiation.

2.4 Fatigue tests

Fatigue tests were carried out by a rotating bending fatigue machine of 98 Nm in load capacity and about 3600 rpm in cyclic speed in laboratory atmosphere. 10^7 cycles were taken as limiting number for evaluation of the fatigue strength.

3. RESULTS AND DISCUSSION

3.1 Variation of shot peening parameter

3.1.1 Hardness distribution Fig. 3 show hardness distributions for the specimens. At shot hardness of Hv 550, surface hardness of the specimens peened with shot A is Hv 747 and that of the specimen peened with shot B is Hv 787.

At shot hardness of Hv 700, those values are Hv 809 with shot A and Hv 818 with shot B. No differences appear in the hardness profiles between two types of shots except for near the surface in both shot hardness level. It is noted here that increasing shot hardness from Hv 550 to Hv 700 results in the surface hardness increase of Hv 30 and Hv 50.

3.1.2 Residual stresses distribution Fig. 4 (A) and (B) show residual stresses distribution for specimens shot peened by Hv 550 shots. No difference was observed between shot A and B. As compared to as carburized specimens, shot peening increases the surface compressive residual stress value to -393 MPa with shot A and -416 MPa with shot B , which results in about 200 MPa increase. Shot peening also increases the maximum residual stress value by -800 MPa to -945 MPa with shot A and -1006 MPa with shot B. At shot hardness of Hv 700, as compared to specimens peened with shot hardness of Hv 550, high hardness shots increase the maximum value to -1163 MPa with shot A and -1338 MPa with shot B. It means 250 and 300 MPa increase, respectively. The change of these profiles by shot peening was observed to the depth of about 150 μm. At high hardness shot, maximum residual stress value had distinct difference between shot A and B. As mentioned above, it seems that this is derive from the difference in shot mean diameter.

3.1.3 Retained austenite Table 4 indicates the results of retained austenite measurement after shot peening with each shots. In the unpeened state, the amounts of retained austenite is a value of 27.8 % at the surface. As it is suggested [5], the content of retained austenite also decreased to 3.9 % - 9.5 % by shot peening in this study.

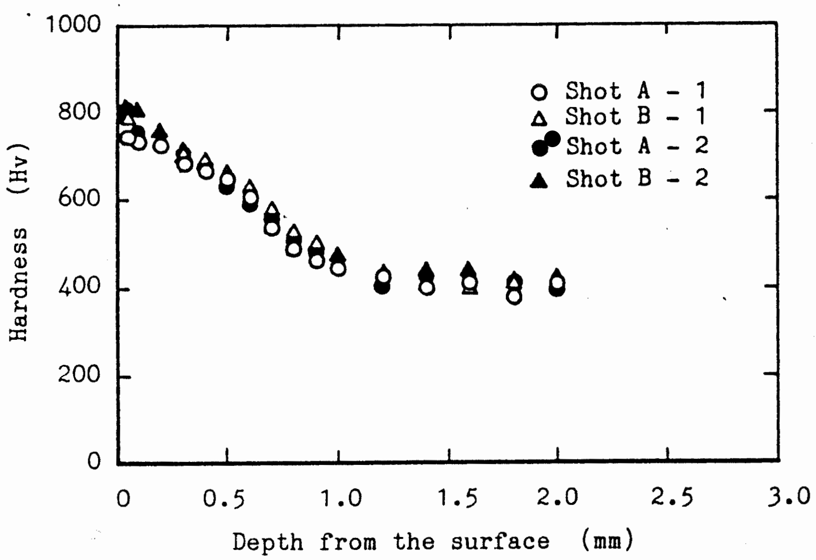

Fig. 3 Hardness distribution

Table 4 Retained austenite

Vγ (%)

As carburized	A - 1	B - 1	A - 2	B - 2
27.8	4.1	9.5	6.9	3.9

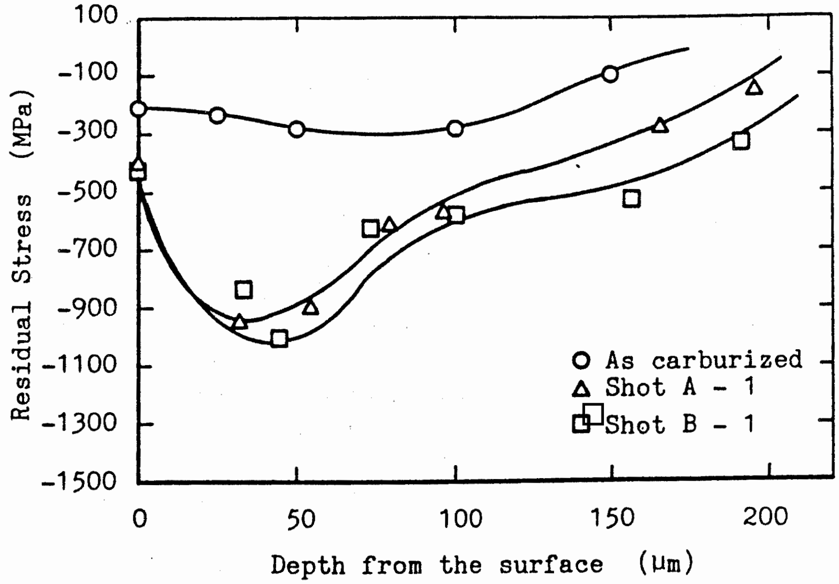

Fig. 4 (A)
Resicual stress distributioin for specimens peened by Hv 550 shots

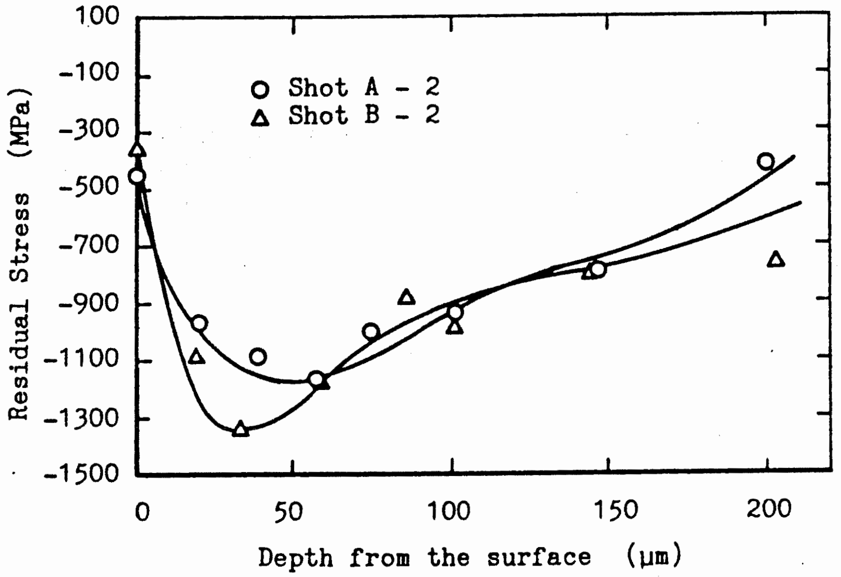

Fig. 4 (B)
Residual stress distribution for specimens peened by Hv 700 shots

3.2 Fatigue tests

3.2.1 S-N curves Fig. 5 shows the results of the rotating bending fatigue test of notched specimens shot peened using Hv 550 shot with Almen intensity of 0.7 mmA. The results of as carburized specimens are also shown. The fatigue strength for 10^7 cycles of the as carburized specimens is 470 MPa and those of the shot peened with shot A and B are both 700 MPa. It means the shot peening with an Almen intensity of 0.7 mmA gives 45 % increase in the bending fatigue limit. No difference was observed in S-N curve between shot A and B.

Fig. 6 shows the test results with shot hardness of Hv 700. 10^7 cycle fatigue limit was 870 MPa and shot peening with high hardness with an Almen intensity of 1.0 mmA leads to a 26 % increase compared to the results of shot hardness of Hv 550. The increase in fatigue strength of specimens with shot B is higher than those of specimens peened with shot A. It is explained that the difference of the results is due to the higher maximum residual stress of peened specimens with shot B than that of peened with shot A, previously shown in Fig. 4 (B).

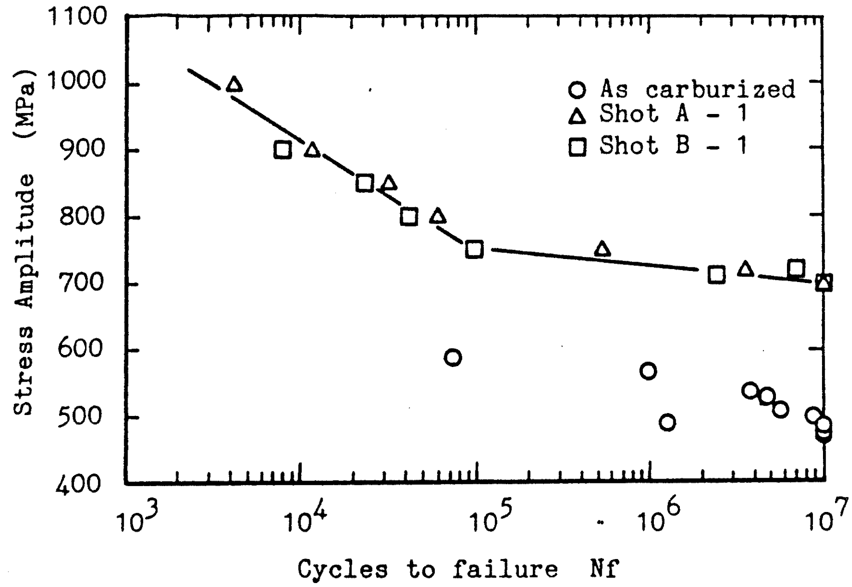

Fig. 5
S-N curve of shot peened using Hv 550 shots with arc height 0.7 mmA and as carburized specimens

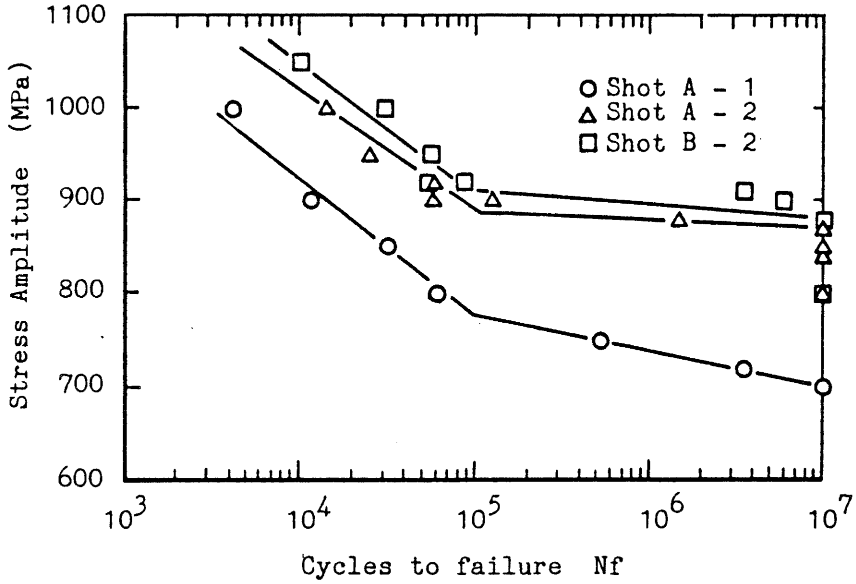

Fig. 6
S-N curve of shot peened using Hv 700 shots with arc height 1.0 mmA

3.2.2 Weibull analysis It is estimated that broken shots during shot peening reduce the peening effects and degrade the stability of the peening effects. So fatigue test with 9 or 10 pieces of shot peened specimens were carried out at the same stress to obtain the weibull charts. The stress where 10^5 life is obtained was selected from the previously shown S-N curves.

Fig. 7 shows the P-Nf curves of the specimen tested at 784 MPa, where the specimens were shot peened by Hv 550 shots. Although samples peened by shot A showed a little longer life than those by shot B, it is noted here that the difference in the life is smaller than expected from the amount of broken shots evaluated by Ervine test. The reason for this results is seemed that broken shots were almost removed out from the actual peening machine and no broken shots effectively bombarded the specimens. In the P-Nf curves fatigue strength of specimens peened with shot A is higher than those of specimens peened with shot B, in spite of the results that hardness and maximum residual stresses of shot B is higher than those of shot A. We cannot make clear the reason for this results in this study.

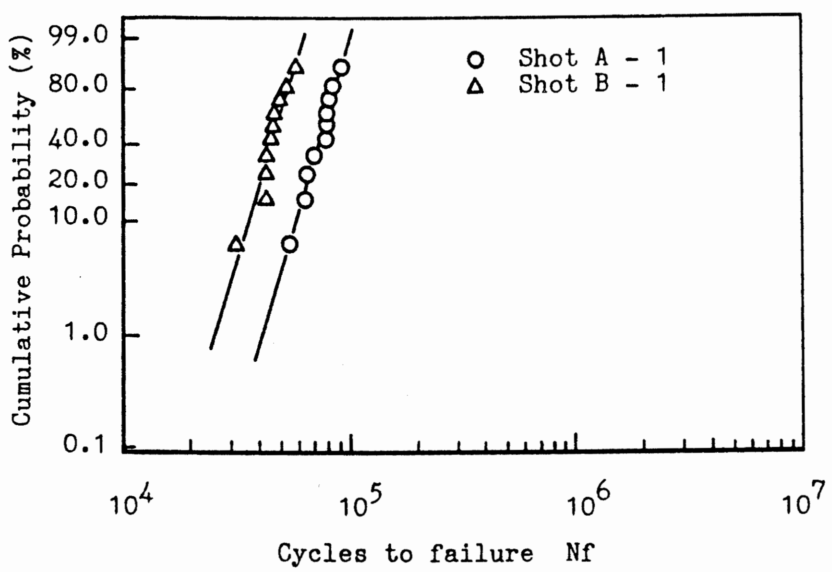

Fig. 7
The P-Nf curve of shot peened by Hv 550 shots

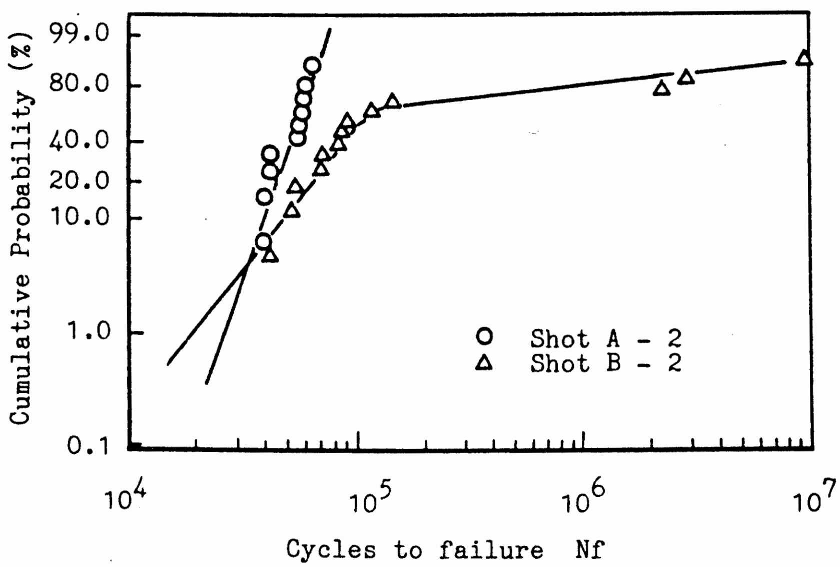

Fig. 8
The P-Nf curve of shot peened by Hv 700 shots

Fig. 8 shows the P-Nf curves of the fatigue test at 920 MPa using the samples peened with Hv 700 shots. The fatigue specimens peened with shot B containing many broken shots show obviously degraded fatigue properties compared to those peened with shot A. The reasons for this results are considered as follows. The first reason is that as the peening time of the specimens peened with shot A are twice as long as those of the specimens peened with shot B, increased coverage reduces the scattering of fatigue strength. The second reason is derived from the facts, as shown in table 2, shot B was consist of extremely large amount of broken shots. Therefore, the capacity of removing broken shots from the peening machine was insufficient and the machine had much broken shots in it when using shot B. To study the first reason, the shots having same mean diameter to that of shot B were prepared to obtain the same peening time (A-3). The peening time with shot A-3 was 4.5 min. Fig. 9 shows the P-Nf curve of the fatigue test for specimens peened with shot A-3 and A-2. As no difference appeared in the results, it was confirmed that peening time gives no influence on the above results. To study the second reason, the relation between the order of shot peening treatment and the fatigue life is considered, which is shown in Fig. 10. Although the number of cycles to failure of specimens peened with shot A remain unchanged, those of peened with shot B decrease as the order of shot peening increase. It seems that the amount of broken shots in the machine increase with increase in the order because of shortage of the capacity removing broken shots and these broken shots decrease the peening effects. Therefore, the distribution of particle size for two types shots before and after shot peening treatment is studied and shown in Fig. 11. The results of shot A remain unchanged, but the results of shot B indicate that retained weight % of shot over 840 μm decreases from 93.75 % to 56.5 % and those of shots under 840 μm and over 710 μm extremely increase from 6.25 % to 41.9 % by increasing broken shots. The reason of the scattering of fatigue strength for specimens peened with shot B at shot hardness Hv 700 is concluded that increased amount of broken shots during shot peening treatment gradually decrease the shot peening effects.

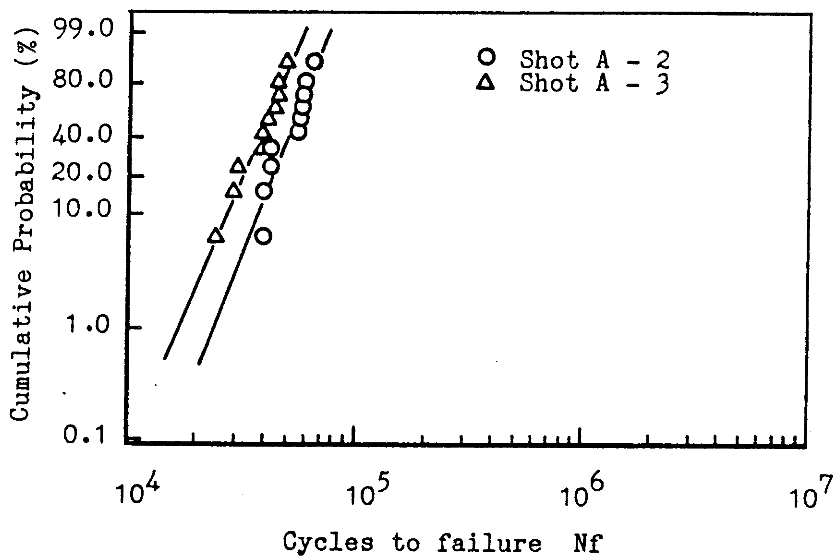

Fig. 9
The P-Nf curve of specimens peened by A-2 and A-3 shots

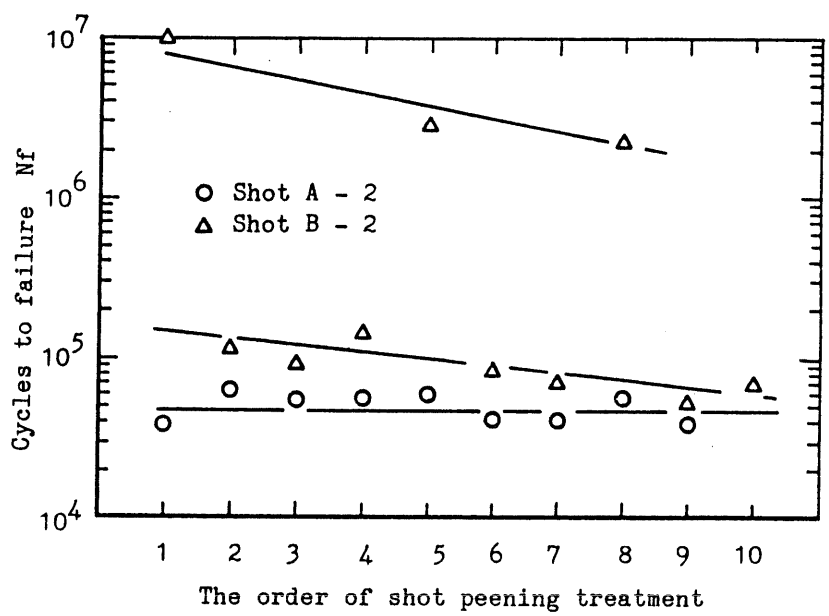

Fig. 10
Relation between the order of shot peening treatment and fatigue life

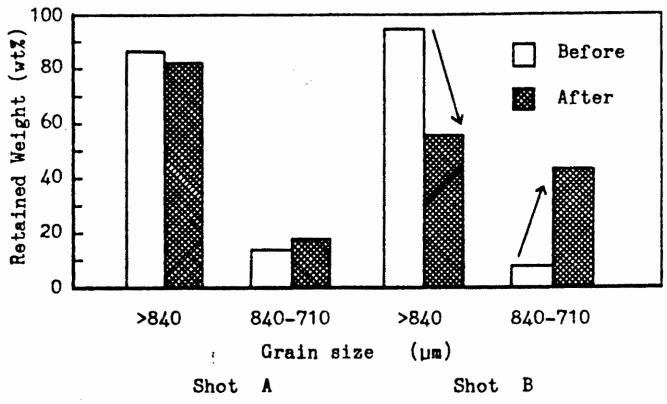

Fig. 11 The distribution of shot particle size for A-2 and B-2 shot before and after shot peening treatment

4. CONCLUSION

The test results are summarized as follows;

(1) As shot hardness increases from Hv 550 to Hv 700, the peening effects on hardness and residual stresses increase. High hardness shots contribute to about 26 % increase in fatigue limits of specimens.

(2) At the shot hardness of Hv 550, it is observed no influence of broken shots on fatigue strength. The peened specimens obtain stability shot peening effects by removing broken shots.

(3) At shot hardness of Hv 700, the specimens peened with shot B consisting of many broken shots show more scattering of peening effects than those with shot A having a little broken shots. The reason of this scattering is concluded that increased amount of broken shots during shot peening treatment gradually decrease the peening effects

In the application of hard shot peening, to get the stable peening effects, it is necessary to use the no broken shot, or to remove the broken shots from the shot peening machine.

5. REFERENCES

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