DEVELOPMENT OF HARD AND TOUGH STEEL SHOT

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ABSTRACT

In order to enhance the performance of machines, steel components have been shot peened, recently very hard with the arc height more than 0.7mmA. Such a process requires hard shot media around HV700, especially for peening on case hardened components. Generally the harder media become more brittle and so shorter lives. The authors have succeeded in developing hard and besides tough cast steel shot produced by centrifugal atomizing. The reduction of C content revealed the most effective to improve the toughness of particles. Therefore, the newly developed steel shot contains 0.5%C, instead of 0.8%C in conventional one, and also 0.5%Si and 0.3%Mn. The hardness of the new grade shot remains HV700 and the life of it extends to four times of conventional one's. The peening effect of the new grade proved to be the same as conventional one's for the gears in JIS SCM420(SAE4118) carburized and shot peened with the arc height 1.0mmA, that is, the residual compressive stress and fatigue strength are analogous to those of gears peened by conventional steel shot.

KEY WORDS

Shot peening, Hard shot peening, Fatigue strength, Toughness, Cast steel shot, Centrifugal atomizing, Residual stress.

INTRODUCTION

Shot peening itself is not always a new cold working process in which the surface of a component is work hardened and compressively stressed by the bombardment of small particles. Because of its advantage to improve fatigue resistance, this technology has been applied to the wide variety of machine structual components[1][2]. Furthermore, it is attracted a great deal of attention as one of the promising strengthening methods, since automobile components have been desired to withstand high loads with the trend in high powered engine or down-sized components. To meet this demand the new carburizing gear steels, for instance, have been developed, the principal concepts of which are the reduction of intergranular oxidation and the improvement of case strength[3]. Although hard shot peening is also an expected countermeasure[4]-[7], there remains a problem such as surface roughness in case of conventional carburizing steels which have anomalies on their surface[8]. High performance new carburizing steels, under this situation, combined with the hard shot peening technology have been applied to highly stressed gears utilizing the advantage that new steels are unsusceptible to surface roughening because of their intergranular oxidation free case[9].

On the other hand, harder peening media are needed as hard shot peening to hard components becomes more and more popular[10]. It is generally confirmed, however, the harder shots become, shorter their endurance life, resulting in the production cost increase. Besides, broken shot not only reduces the peening effect but also endangers to damage the surface and decrease in fatigue life[11].

In accordance with these background, we have carried out the research and development on the long life high hardness cast steel shot. In this paper the fracture analysis of conventional cast steel shot, the alloy design of the new grade shot and the application tests are reported.

FRACTURE ANALYSIS OF CAST STEEL SHOT

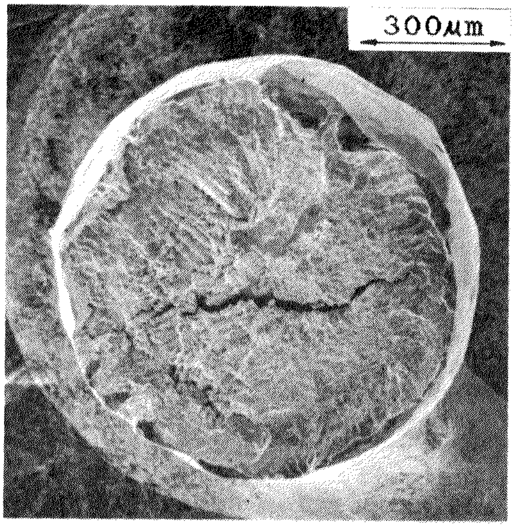
The example of chemical composition of conventional cast steel shot recommended by SAE-J827 is shown in Table 1. 0.85-1.20% C steel is classified as hyper eutectoid steel and suitable for wear resisting use.

Table 1 Chemical composition of Cast steel shot (wt%)

C	Si	Mn	P	S
0.85/1.20	min.0.40	0.60/1.20	max.0.050	max.0.050

(SAE J827)

We observed, at first, the fracture surface of broken shot which were injected with a conventional intensity such as arc height 0.45mmA. Photo. 1 shows the microfractogragh of the conventional 1.0%C-0.8%Si-0.8%Mn steel shot.



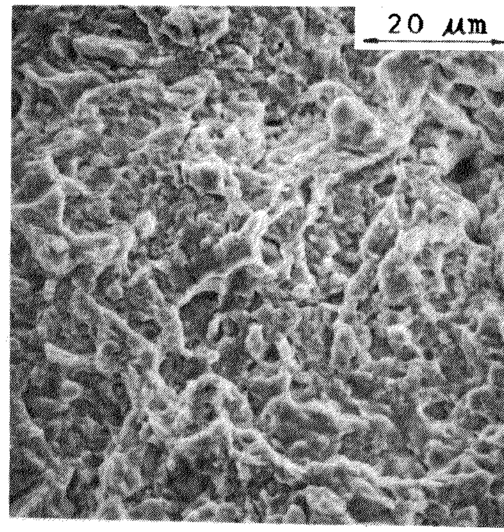


Photo.1 SEM fractographs of fractured conventional shot

It was revealed that the fracture surface was composed of micro void coalescence mode initiated from carbide and dendritic cast structure. The dimple pattern obtained here is characterized by its smooth and shallow one with less plastic deformation because of the large number of carbide particles. Furthermore, the study on the effect of hardness on the life of conventional shot revealed that shot exhibits shorter life with increasing hardness. According to these informations, an alloy design of cast steel shot was tried mainly from the view point of improving toughness. Therefore, it is desirable to reduce the carbide precipitates by decreasing carbon contents and to refine dendritic cast structure in order to prolong the shot life.

EXPERIMENTAL PROCEDURES

At first, we examined the chemical composition of cast steel shot, to enhance the toughness. Test steel shots were melted by arc furnace and water atomized. After optimizing the chemical composition, new grade shot was melted by arc furnace and cast by centrifugal atomizing method. The purpose of this new atomizing process was to increase shot life by refining the dendritic structure in casting. Shots were screened by the range of 0.84 to 1.00mm diameter and hardened and tempered to HV700. Tempering was carried out at 150 to 250°C depending on the carbon contents of test steel shots. Shot life was evaluated by Ervin test machine. Ervin test was carried out by the stabilized loss method, in which 100g of prepared shots were peened with 7050rpm wheel speed. The screen size was 0.71mm. And another peening machine life test was performed by using the centrifugal type actual peening machine, and by measuring the broken shot quantity with peening time. The transmission electron microphotograph and microfractograph were taken for the discussion. The specifications of shot peening machine are shown in Table 2.

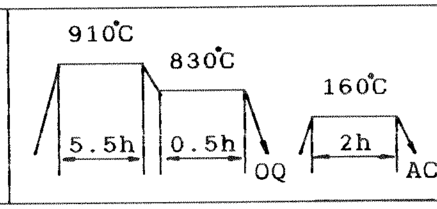
Table 2 Specifications of shot peening machine

Machine type	Centrifugal type
Maximum shot flow	220kg/min
Wheel speed	570-2280rpm
Shot speed	25.1-100.6m/sec
Turn table speed	12rpm

Shot peening properties of the new grade shot were studied as a next step. The peening intensity, hardness profiles, and residual stress profiles of peened pieces were examined. As test pieces JIS SCM420 carburized and tempered blocks sized 8h x 19w x761 mm were used. Residual stress distribution was obtained by repeating the X-ray measurement and electrochemical polishing. The residual stress measurement was performed by X-ray difraction technique, the $\sin^2\psi$ method. The 8x8mm area of the test specimen was electrochemically polished and X-ray measured. Furthermore, gear fatigue properties were obtained to confirm the peening effect on fatigue strength. Gear fatigue test was performed by the power circulated type gear fatigue testing machine. Test gears were spur ones. Carburizing and tempering conditions are shown in Table 3.

Table 3 Dimension of test gears and carburized condition

Dimension	pinion	gear
Module	2.5	2.5
Number of teeth	28	32
Pitch circle(mm)	70	80
Pres. angle(deg)	20	20



RESULTS AND DISCUSSION

The design of new steel shot

According to the informations obtained from the fracture analysis that cast steel shot life was governed by toughness, an alloy design was tried from the view point of increasing hardness and toughness at the same time by testing mainly the carbon content ranged from 0.4 to 1.1wt%. Silicon and manganese contents were varied to study productivity and shot life. Furthermore, phosphorous and sulfer were reduced to decrease the segregation to austenite grain boundary and MnS formation, respectively[3]. The chemical compositions of test steel shots are shown in Table 4. Figure 1 shows the relative life of the test shots evaluated by Ervin test machine. The relative life used here is defined as the ratio of each life to 0.85%C shot life which is determined to be 100. It is confirmed there exists negative corelation between carbon content and shot relative life, which indicates that decreasing carbon content has the advantage of increasing shot life. It should be noted, however, carbon content higher than 0.5% is needed to obtain the hardness HV700.

Table 4 Chemical composition of test steel shots (wt%)

C	Si	Mn	P	S
0.70	0.60	0.90	0.010	0.004
0.56	0.90	0.50	0.010	0.004
0.91	0.60	0.90	0.010	0.005
0.58	0.40	0.40	0.010	0.004
0.61	0.50	0.40	0.010	0.005
0.50	0.50	0.40	0.010	0.004
0.67	0.30	0.70	0.010	0.004
0.65	0.80	0.40	0.010	0.004
0.66	0.90	0.80	0.010	0.004
1.05	0.72	0.95	0.024	0.018
0.85	0.60	0.50	0.030	0.029

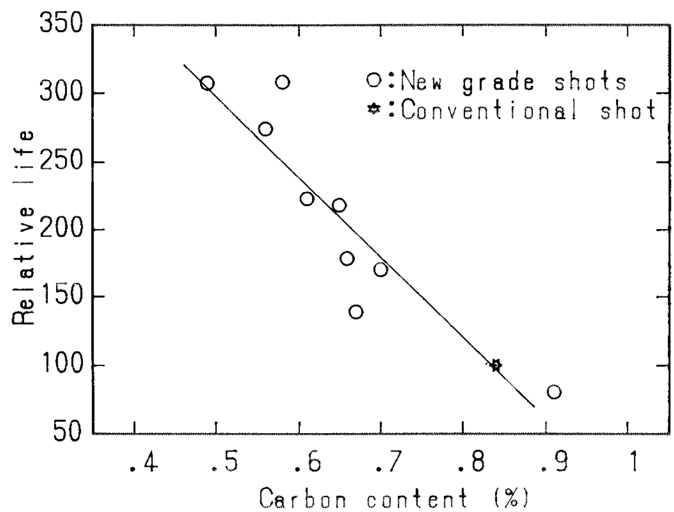


Fig.1 Relation between relative life and the carbon content of test steel shot

And it is also clarified that decrease in silicon and manganese content is preferable for shot durability without being accompanied by the troubles in production. Further study on the effect of nickel, chromium and molybdenum indicated that these elements, especially nickel and molybdenum, are favourable for prolonging the shot life. The relative life of 0.5%C-0.5%Ni-0.3%Cr shot, for instance, was about 650. However, these elements are not added to the new grade to prevent the production cost up.

Properties of the new grade steel shot

The chemical composition of the new grade cast steel shot and conventional cast steel shot which was used as comparing shot are shown in Table 5. Conventional one was obtained as commercially produced.

Table 5 Chemical composition of the new grade test shot (wt%)

Steel shot	C	Si	Mn	P	S
New grade	0.50	0.50	0.32	0.011	0.007
Conventional	0.80	0.48	0.47	0.025	0.026

Figure 2 shows the relative life of the new grade evaluated by Ervin test machine. The relative life is a standarized value by using the conventional steel shot data of HV700. The hardness of the new shot was varied by tempering. The new one's life is about three times as long as that of conventional shot in HV700 hardness.

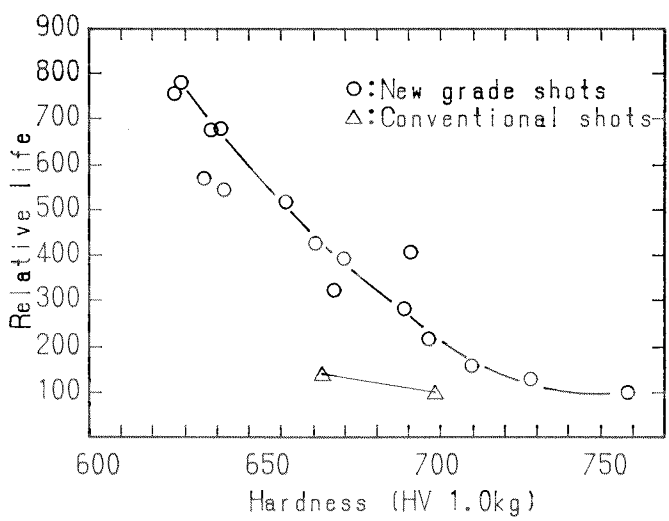


Fig.2 Relative life of the new grade shots evaluated by Ervin test machine

Electron micrographs of the new and conventional shots are shown in Photo. 2. Both of the shots are consist of tempered martensite and precipitated carbides. But the new grade contains smaller amount of carbides than conventional ones. Photo. 3 shows the scanning electron micrographs obtained from fracture surface. The new grade has no appearance of dendritic structure and the fracture mode is composed of intergranular and transgranular ones. As a result, the prolonged shot life in the new grade is considered due to the toughness improvement by low carbon content and the refined cast structure by applying the centrifugal atomizing methods.

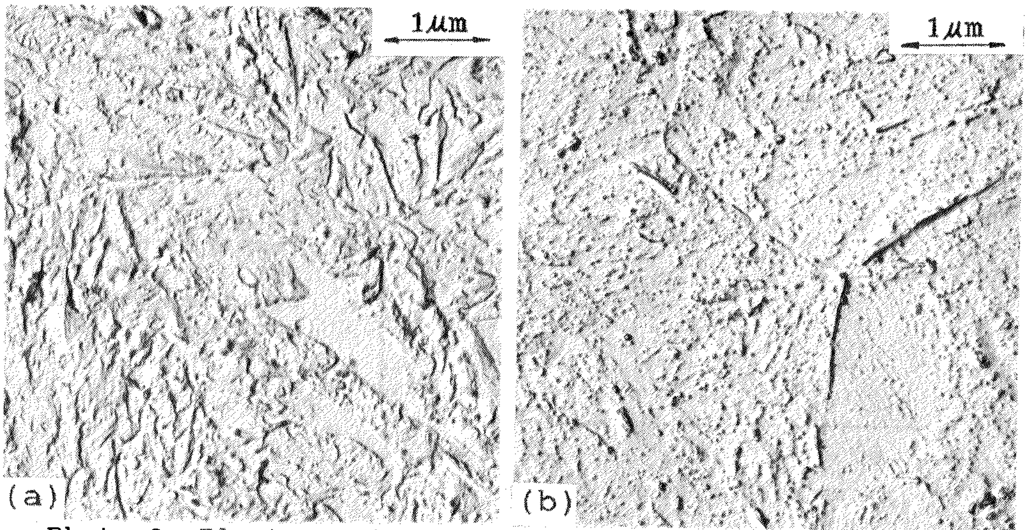


Photo.2 Electron micrographs of cast steel shots
(a) Conventional shot (b) New grade shot

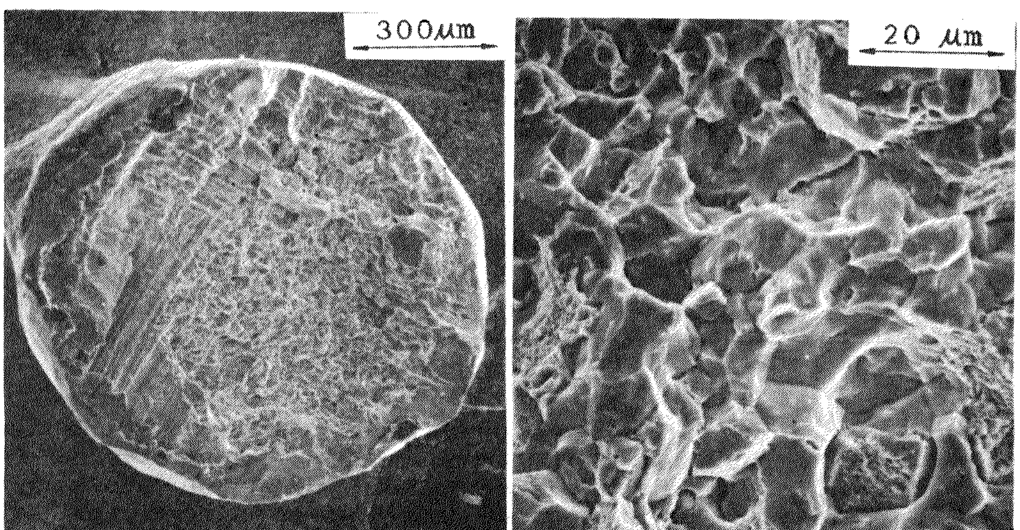


Photo.3 SEM fractographs of fractured new grade shot

Figure 3 shows the comparison of the shot life obtained from the actual peening machine test, which was performed with a shot flow of 45kg/min at the speed 106m/sec. The same result as that of Ervin test was confirmed that the new grade exhibited three to four times longer life than conventional one in the case of hard shot peening. Almen A intensity obtained by the new grade is shown in Fig. 4. As there is no difference to be seen between them, the new grade can be in practical use in the same manner.

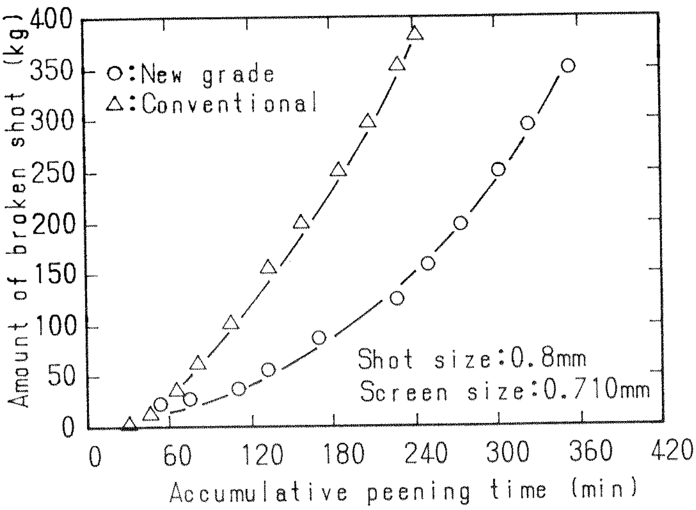


Fig.3
Comparison of steel shot life evaluated by the peening machine

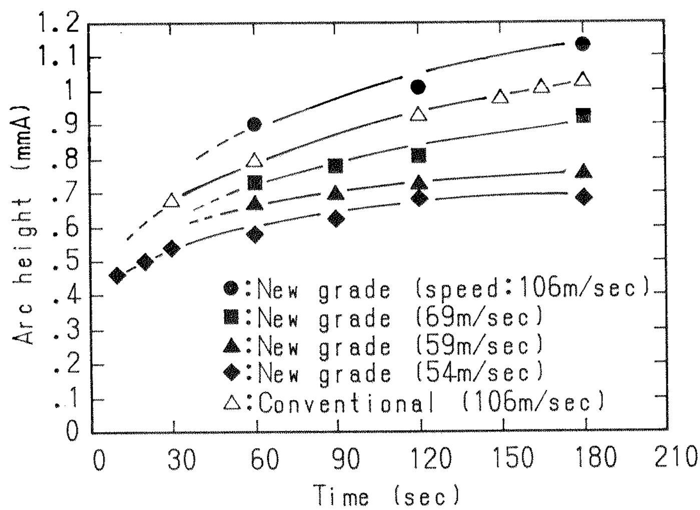


Fig.4
Almen intensity of the new grade shot

The peening effect of the new grade was studied, as the next step,by using carburized SCM420 specimens. Figure 5 shows the hardness profiles of test pieces peened by HV700 shots with 0.7mmA intensity. The new grade shot gives almost the same hardness profile as conventional shot does. Figure 6 shows the residual stress profiles for the test pieces peened by HV700 shots with arc height of 0.45mmA and 0.7mmA. No differences are observed in both of the peening intensity between the new grade shot and conventional one.

Since the new grade shot was confirmed not only to show long life but also to give the same peening effect, gear fatigue test was carried out using the hard shot peened gears. Figure 7 shows the gear fatigue test result, the relation between tooth root bending stress and the number of cycles to fracture. The shot peening was carried out by using the HV700 new grade shot with 1.0mmA intensity. And the coverage was 300%. The fatigue strength of the hard peened gears is higher than as carburized tempered gears by 25%. And this increment is in good agreement with the previous result.

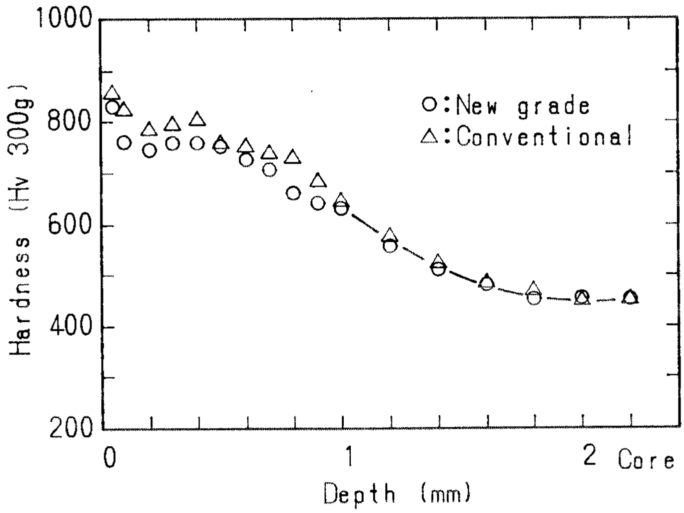


Fig.5
Hardness profiles

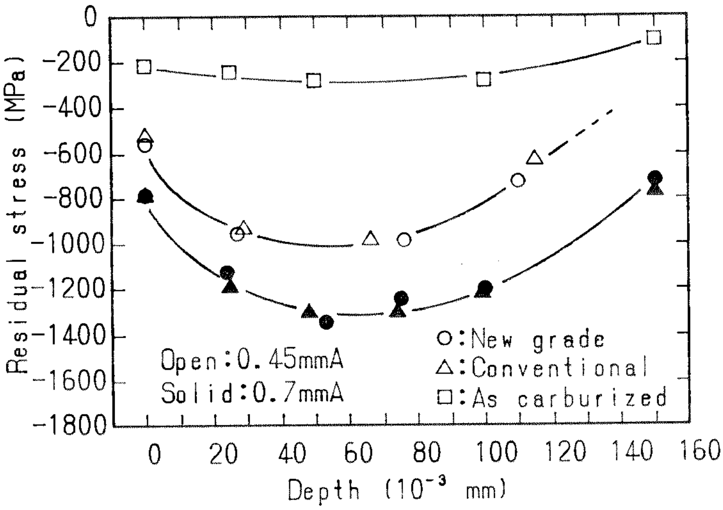


Fig.6
Residual stress
profiles

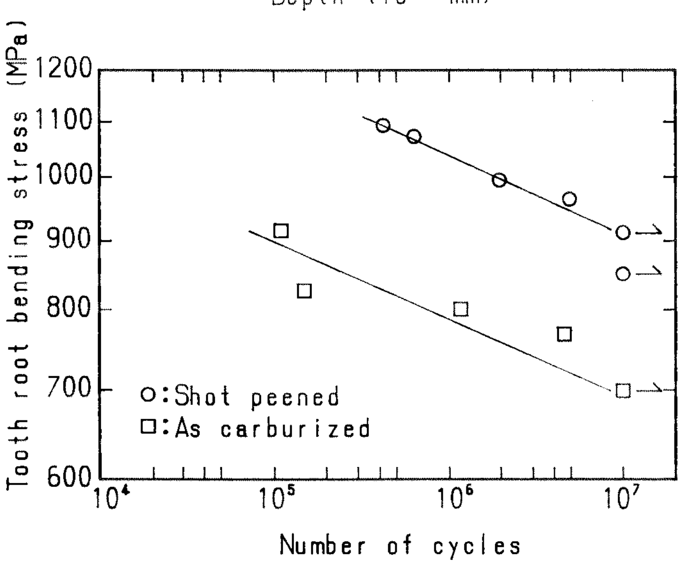


Fig.7
Gear fatigue
properties

CONCLUSIONS

The hard and tough cast steel shot which is suitable for hard shot peening process has been developed. The conclusions obtained from this work are as follows.

(a)The chemical composition of the new grade shot is 0.5%C-0.5%Si-0.5%Mn-P<0.015%-S<0.010%. This steel shot is characterized by decreasing carbon, austenite grain embrittling element P, and Mn and S content to enhance the toughness.

(b)The new grade shot shows three times longer life than conventional shot in Ervin test machine. Another life test performed by actual peening machine gives the same result that the new grade is three to four times longer than conventional one.

(c)As for the peening effects on the carburized components, the performance of the new grade is almost the same as those of conventional one in terms of peening intensity, hardness profiles, and residual stress distribution.

(d)Gear fatigue test of the carburized gear peened with the new grade shows reasonable increase in fatigue strength. Therefore this new grade shot is expected in practical use as one of the promising peening media.

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