# Effect of Shot-Peening on fatigue Strength of Metals. II : Effects on Decarburized Steels

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# Effect of Shot-Peening on fatigue Strength of Metals: II
# Effects on Decarburized Steels*

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**Synopsis**

The effect of shot-peening on the fatigue strength of decarburized Si-Mn spring steels was examined by the rotary-bending and the reversed torsional method. The effect was very striking and it was observed that the endurance limit at $10^7$ cycles of decarburized steels, which was reduced by about 50 per cent of limit of the polished specimen on account of the soft layer only about 0.05 mm in thickness, increased by 40∼50 per cent as the result of shot-peening of the decarburized layer. It might be possible to recover the strength in the non-decarburized state by increasing the peening intensity.

## I. Introduction

The fatigue strength of metals and alloys depends besides chemical compositions and heat-treatments, largely on the surface state of the material. It is, therefore, necessary for machine parts subjected to repeated loading to protect or strengthen the surface layer from which the fatigue fracture begins. For this purpose such methods as carburizing, nitriding, induction surface hardening and shot-peening have been suggested and put into practice. Of these the shot-peening is comparatively simple in treatment, and is of high flexibility with a wide range of application. Therefore, it is of value to investigate the effect of shot-peening under various conditions.

In the previous study[(1)], it was seen that a hardened layer was formed on the surface of a specimen by shot-peening, resulting in a positive effect on the fatigue strength, while the surface roughness due to the stamping of steel balls resulted in a negative effect, the combined result being that the fatigue limit and the endurance life increased greatly compared with those in mere polished state, not only in the case of iron and steel but also in the case of non-ferrous alloys. In most case, however, the iron and steel have a scaled and decarburized layer in the surface during the manufacturing process. Even in the case of a bearing spring for car, which is a typical example in which repeated stress is given all the time while in use, only quenching and tempering are possible after heating and forming, and further work of polishing and finishing is, in fact, impossible. Thus, the

* The 926th report of Research Institute for Iron, Steel and Other Metals.

(1) S. Takeuchi and T. Homma, Sci. Rep. RITU, **A10** (1958), 426 ; J. Japan Inst. Metals, **22** (1958), 14.

surface of a leaf spring or a coil spring always has a decarburized surface layer. It is, therefore, quite natural that the fatigue strength should remarkably fall, provided that they are used without further treatments. It will, however, be expected that if shot-peening is worked on it, the fatigue strength will greatly be improved even when there exists a decarburized layer.

Such being the case, the present experiments were carried out clarify the effect of shot-peening on steels with a decarburized layer.

## II. Experimental procedure

1. Specimens and fatigue tests

Two kinds of fatigue test, namely, rotary-bending and reversed torsion, were carried out with Si-Mn spring steels of JIS Sup-6, of which the chemical composition, heat-treatment and mechanical properties are shown in Table 1. Shapes

Table 1. Chemical composition, heat-treatment and mechanical properties of specimens

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Chemical composition % | C | Si | Mn | P | S | Cr | Cu | % |
| | 0.54 | 1.50 | 0.81 | 0.007 | 0.013 | 0.034 | 0.27 | % |
| Heat-treatment of specimen | (a) 850° 60min heating and furnace cool<br>(b) 850° 30 min heating and Oil-quenching<br>520° 60 min tempering and air-cool | | | | | | | |
| Mechanical properties | Tensile Strength $\sigma_B$ kg/mm² | Yield Strength $\sigma_S$ kg/mm² | Elongation % l=8d | Reduction % | Impact Value Charpy kg-m/cm² | Hardness Rockwel-C | | |
| | 143.5 | 118.7 | 11 | 28 | 3.8 | 42 | | |

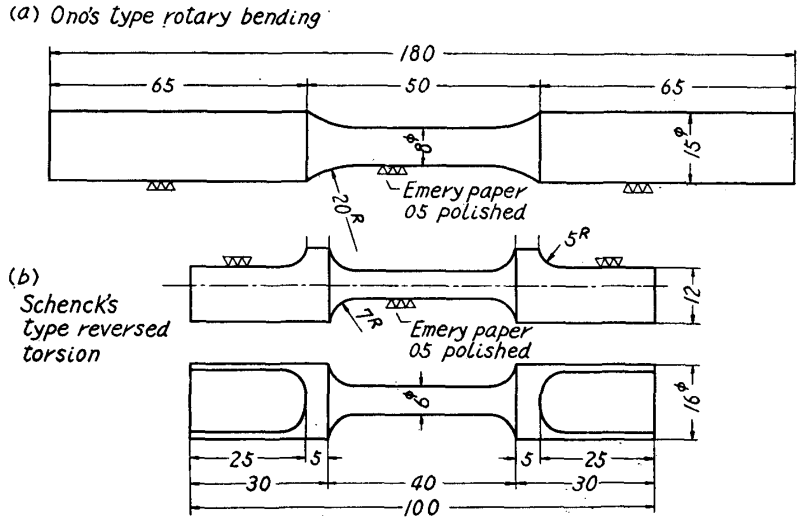


Fig. 1. Shapes and dimensions of fatigue specimens.

and dimensions of the specimens are shown in Fig. 1. The polished specimen was quenched and tempered with a slim margin of 1 mm left, and then its paralell part and grip part were finished up to the specimen size and polished up to the degree of emery paper 05. As for a shot-peening specimen, only the parallel part was polished and finished, and then peening was applied to it, and finally the grip parts were finished. As for a decarburized specimen, only the parallel part was polished up to the degree of emery paper 05, and after heating in electric furnace for 30 minutes at 850°C, it was oil-quenched and tempered. Every effort was made in finishing the grip parts to avoid distortions and bends which might be caused by heat-treatment. As for the peening specimen, only its grip parts were finished after decarburization.

For fatigue tests rotary-bending machine of Ono-type and reversed torsion machine of Shenck-type were used. The testing speed was 2000 rpm in the former and 3000 rpm in the latter. As Schenk machine is of deflection-constant-type, the stress varies little by little, but it may safely be said that the change in the stress would be the least in the present case, because the materials were spring steels of high yield strength and elastic limit. Especially in the case of a decarburized specimen, much smaller stress would serve the purpose than that the in the case of a polished specimen, and so, the deflection of the stress bar would be constant until the fatigue caused cracks. Accordingly, the tests may fairly be said to be under the condition of constant stress. Furthermore, in the case of rotary-bending test, some bends in a decarburized specimen due to the heat-treatment were not perfectly removed, and accordingly, the vibration might increase a little, but when the eccentricity was less than $\pm 0.05$ mm, no serious hindrance was observed for the continuation of the experiment.

2. Conditions for shot-peening

The machine of air nozzle type was used for shot-peening and working conditions, shots used and others were the same as those in the previous case(1). In addition, in order to investigate the influence of peening intensity, some experiments were carried out by varying the air pressure and the conveyer travelling speed, but it is sufficient to show the results obtained from the experiments only for suggestion, because the coverage was so bad that the experiments were not reproducible.

## III. Experimental results

1. Thickness of a decarburized layer

The thickness of a decarburized layer produced only by quenching was first determined from the hardness distribution on the surface cut at the gradient of 1 in 25 to the specimen axis. The result is shown in Fig. 2. As shown in the figure, the hardness of the surface was remarkably low, and the decarburized thickness was about 0.05 mm when the specimen was heated at 850°C for 30 minutes. The decarburized and then shot-peened specimen was hardened nearly up to the hardness of the ground, but the hardness was not perfectly recovered by the intensity of the present peening.

2. Results of the fatigue tests

Four kinds of fatigue tests were carried out: first, with a specimen whose parallel part was polished and finished up to emery paper 05, by way of setting up a standard for decarburized specimens; second, with a specimen made by shot-peening after polishing ; third, with a decarburized specimen whose parallel part only was first finished and then undergone heat-treatment; fourth, with a specimen subjected to shot-peening. Fig. 3 shows S-N diagrams in rotary-bending tests. The results are summarized in Table 2. In the case of rotary-bending, the effect of peening upon a polished specimen was only of about 3 per cent rise in the fatigue limit at $10^7$ cycles, being from 59 to 61 kg/mm$^2$, but the fatigue limit of a decarburized specimens as heat-treated was 31 kg/mm$^2$, falling nearly half as much

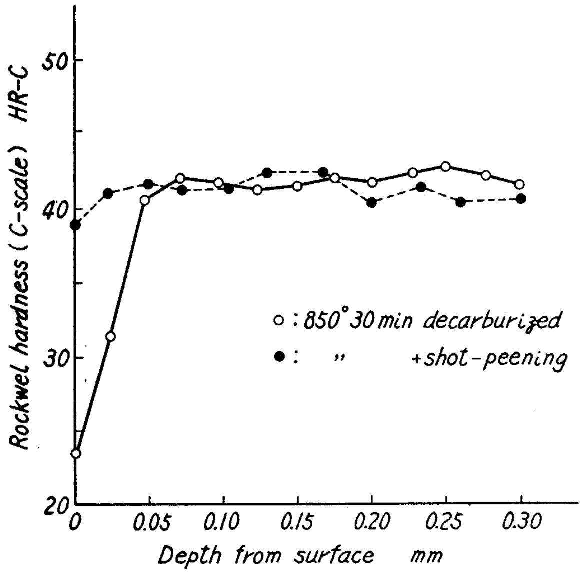


Fig. 2. Influence of shot-peening on the distribution of surface hardness of decarburized Si-Mn spring steel.

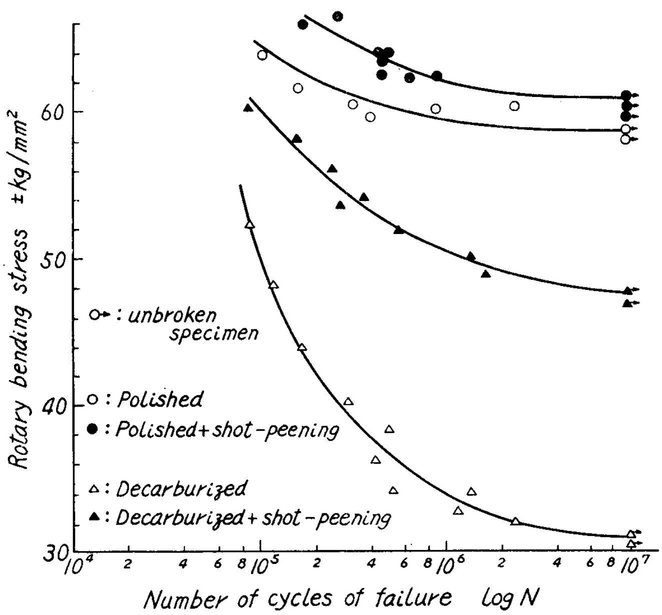


Fig. 3. Effect of shot-peening on the S-N diagram of decarburized specimens under rotary bending fatigue test.

as the value of the polished specimen, owing to the decarburized layer of 0.05 mm or so. When the shot-peening was worked on this, the fatigue limit rose to 48 kg/mm$^2$, showing an increase of 54 per cent, as compared with that of the decarburized specimen. When they are compared with one another in the number of

Table 2. Summary of fatigue testing results

| Fatigue test | Fatigue limit of polished specimen ± kg/mm² | Fatigue limit of shot-peening specimen ± kg/mm² | Increase of polished fatigue Limit % | Fatigue limit of decarburized specimen ± kg/mm² | Fatigue limit shot-peening specimen ± kg/mm² | Increase of decarburized fatigue limit % |
|---|---|---|---|---|---|---|
| Rotary bending | 59 | 61 | 3 | 31 | 48 | 54 |
| Reversed torsion | 41 | 42.5 | 3 | 23 | 33 | 43 |

cycles to the rupture under the same stress, it can be seen more distinctly that the effect is striking. Under the stress of $\pm 50\,kg/mm^2$, for instance, the decarburized specimen fractured at about $1 \times 10^5$ cycles, while the shot-peened specimen did at $14 \times 10^5$ cycles, showing an increase of life by ten-odd times. Under the stress of $\pm 40\,kg/mm^2$, the decarburized specimen fractured at about $3 \times 10^5$ cycles, that is, after 2 hours and a half, while after peening it could endure to infinite cycles in the laboratory test. Thus, it will be seen how striking an effect is that shows the increase of 54 per cent in the fatigue limit at $10^7$ cycles,

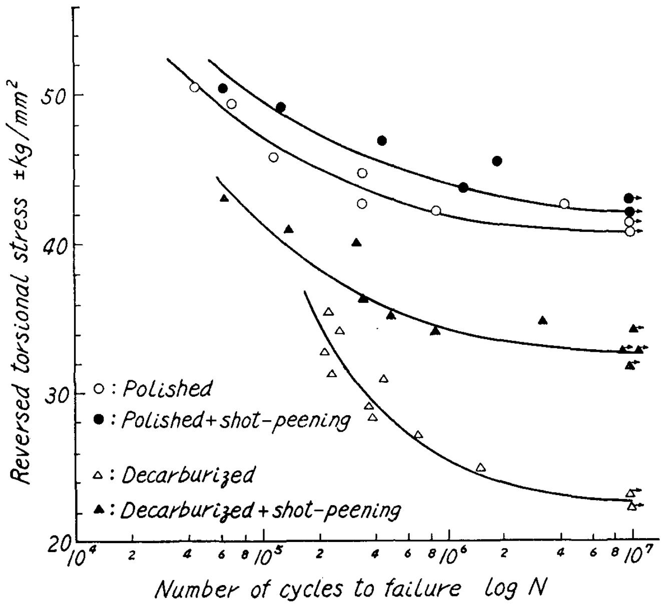


Fig. 4. Effect of shot-peening on the S-N diagrams of polished and decarburized specimens under reversed torsional fatigue test.

namely, by one times and a half.

Quite the same can be said of the case of reversed torsional fatigue. As shown in Fig. 4, the fatigue limit of the polished specimen was $41\,kg/mm^2$, while that of the shot-peened specimen was $42.5\,kg/mm^2$, showing only an increase of about 3 per cent; in the decarburized specimen it was $23\,kg/mm^2$, while in the shot-peened specimen it was $33\,kg/mm^2$, showing an increase of about 43 per cent. When compared in the terms of the life to the fracture under the same stress, the effect will be seen to be as conspicuous as in the case of rotary-bending.

## IV. Considerations of experimental results

As stated above, the existence of a very thin decarburized surface layer lowers the fatigue limit remarkably, which is almost the same as the previous results.[(2)~(5)] It may follow, therefore, that in estimating the quality of high fatigue-resisting steel, the existence of a decarburized layer which may reduce the fatigue strength by half is, above all, a determing factor, being much more important than the metallurgical factor, such as chemical composition or heat-treatment. Accordingly, the allowable thickness of the decarburized layer will be of great significance. Fig. 5 shows the change in the fatigue strength due to the change in the thickness of the decarburized layer. When the specimen quenched at 850℃ after heating for 30 minutes is compared with that quenched at 850℃ after heating at 1000℃ for 30 minutes it will be seen that the thickness of the decarburized layer increases from 0.05 mm to 0.20 mm, but with little or no difference both in S-N diagram and in the fatigue limit at $10^7$ cycles. Estimating from this, the critical thickness that will reduce the fatigue strength by half seems to de thinner than 0.05 mm, and a further increase in the thickness does not make much difference in the fatigue properties.

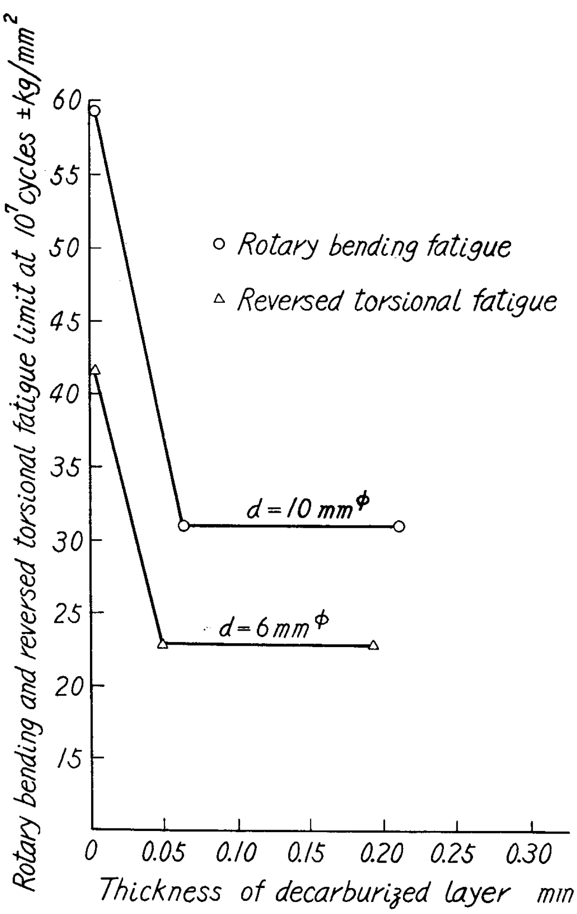


Fig. 5. Relation between the fatigue limit andthe thickness of decarburized layes.

Therefore, if the decarburized layer becomes thicker than the critcal depth, the stress will converge on a fine initial fatigue crack, and as a result, even under much lower stress than the intrinsic fatigue strength of the material, the stress will lead to fracture. Therefore, the higher the hardness of the ground is, or the higher the yield strength and tensile strength, and the more homogeneous the material is, the more conspicuous becomes the effect of the decarburized layer, and in this case the thickness of the decarburized layer seems to be almost in significant. On the contrary, in annealed soft steels, or very thin spring

(2) G. A. Hankins and M. L. Becker, J. Iron Steel Inst., **125** (1931), 387; **131** (1935), 165; **133** (1936), 399.
(3) E. Houdremont and R. Mailänder, Stahl und Eisen, **49** (1929), 833.
(4) R. G. Bradley, Proc. Inst. Mech. Engg., **120** (1931) 31.
(5) A. S. Kenneford and G. C. Ellis, J. Iron. Steel Inst., **164** (1950), 265.

materials, the fatigue limit may gradually decrease with the increase in the thickness of decarburized layer. No difinite quantitative conclusion, however, can be drawn on the relation between the thickness of a decarburized layer and the decrease in the fatigue strength, unless further experiments are carried out by taking into consideration the quality of the material, tensile strength, heating atmosphere, size effect, etc.

Next, the intensity of shot-peening will be considered. This seems to vary fairy with peening-machine. There are too many factors to set up a standard for the degree of working, as they are very complicated. Unlike the centrifugal type, the characteristics of air nozzle type machine are that the cooling effect is effective together with the working of shot-striking by compressed air, and that accordingly, the temperature rise of the peened material is comparatively small; in other words, there is little or no need of apprehension of the so-called "over-peening" that leads to further lowering of the strength of the metal(6). In fact, in the fatigue tests of polished specimens under various conditions of the peening, no striking difference in the fatigue limit and no phenomenon of "over-peening" were observed in the case of air nozzle type machine. However, when soft decarburized surface layer is present, the fatigue limit varies considerably with the peening-intensity. As shown in Fig. 6, the increase in the peening-intensity is attended by a rising tendency of the fatigue strength. In the present case of varying the intensity of peening, however, the coverage also changed so remarkably that the intensity of peening could not be expressed in definite terms, and accordingly, the curve in Fig. 6 is not very trustworthy, which refers to the specimen 10 mm in diameter. The fatigue limit of the decarburized specimen was nearly equal to $\pm 30$ kg/mm$^2$, the value of the specimen 8 mm in diameter, but when peening was worked on it, the limit became 42~43 kg/mm$^2$ in 10 mm specimen, while it was 48 kg/mm$^2$ in 8 mm specimen. It is considerably disparate. Though the reason for it is not clear, it is due probably to the differences in the conditions and intensity of peening.

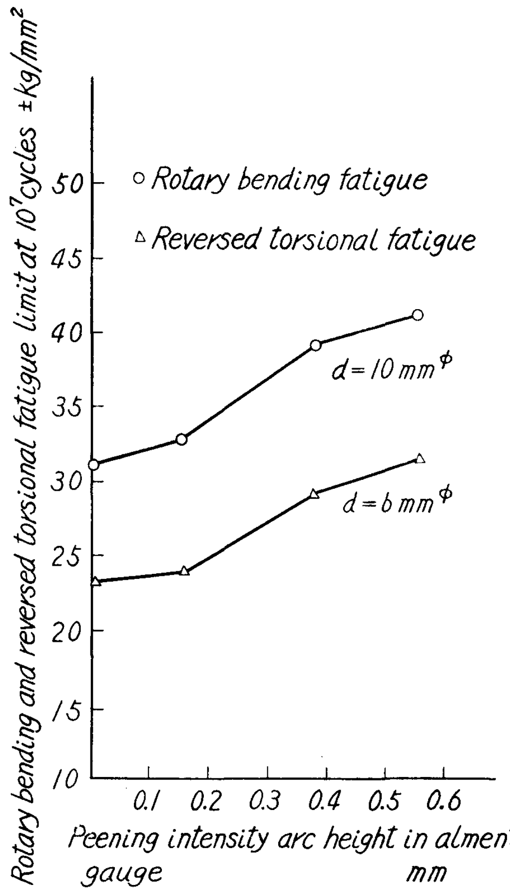


Fig. 6. Influence of peeningintensity on thefatigue strength of decarburized specimen.

There are some reports that by shot-peening a specimen having decarburized layer, its fatigue limit can be raised above to or that of polished specimen.[(6),(7)] In such cases, the first question to come up is the method of making the polished specimen adopted for comparison. Considering that there would be notable differences in the making of decarburized specimen, the conditions of peening, and in the method of fatigue test and the type of stress, it would be difficult to discuss the rate of increase in the fatigue limit merely from the intensity of shot-peening.

Summarizing the above- mentioned, it may be asserted that when there exists a decarburized layer, the effect of peening seems to vary considerably with the intensity of peening, but that somewhat intense peening is more effective, making the fatigue strength gradually approach that of the polished state.

## Summary

By using Si-Mn spring steel the effect of a decarburized surface layer was first investigated, and the effect of the shot-peening worked on it was next examined by the rotary-bending and reversed torsional fatigue tests. The main results may be summarized as follows:

( 1 ) In Sup-6 Si-Mn spring steel heat-treated so as to have the tensile strength of 140～150 kg/mm$^2$, the fatigue strength was reduced by half even by the existence of a decarburized layer only 0.05 mm in thickness. The increase in thickness of the decarburized layer to some degree should little or no difference in the fatigue strength.

( 2 ) When shot-peening was worked on the specimen which the fatigue strength was reduced by half owing to the existence of a decarburized layer, its effect was so striking that a large increase in the fatigue limit of 40～50 per cent was observed at $10^7$ cycles. Furthermore, when a soft decarburized layer existed in the surface, some intense work of shot-peening seemed to be more effective.

## Acknowledgments

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( 6 ) A. Ôno and T. Miyakawa, J. Japan Soc. Test. Materials, **5** (1956), 476 ; **6** (1957), 23.
( 7 ) H. Lüpfert, VDI, **37** (1943), 481.