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Fatigue Strength and Impact Strength of Link-Plates of Chains*

(Received March 25, 1967)

Masataka NAKAGOME**

Abstract

When chains are driven at comparatively low speed, repeated impact loads are imposed on them and often cause fatigue failure.

It is well known that not only the strength of link-plates of chains influences the lives of chains, but also failure of rollers, or of bushes, at high driving speed, and seizure of pins with bushes is caused, when the speed is higher.

Therefore, in this report, several conditions were taken; several shapes of link-plates considered, several methods of finishing at holes were taken and shot was peened, and how fatigue strength and repeated impact strength are influenced was studied.

I. Introduction

According to the results, obtained from fatigue tests by using small-sized roller chains, it has been noted that the weakest parts of chains are the ends of the link-plates.[1)-3)]

It is supposed that the fact is caused by concentrated stresses at the ends of link-plates. Link-plates are the members on which tensile forces applied to chains are imposed, and receive repeated impact loads.

Here, three types of link-plates were taken, and when finishing at holes was considered six conditions were taken and the effects on the fatigue strength were studied. For shot-peening, five conditions were selected in order to investigate how it influences the fatigue and impact strength.

II. Testing machines and link-plates as specimens

Haigh's tension-compression fatigue testing machine of the capacity ± 1 ton was used for the fatigue tests. Pulsating tensile loads were used as the repeated loads and the repeating velocity was 1,450 c/min.

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Matsumura's repeated impact tester with the capacity of 50 kg·cm and a Charpy's impact tester with capacity of 30 kg·m were used for the repeated impact tests. The tested link-plates were as follows; JIS No. 50 link-plates of roller-chains with the minimum width at the central contraction 11.2 mm.

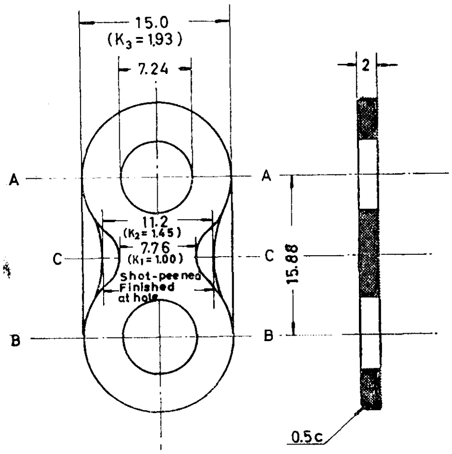


Fig. 1. Main dimentions of all kinds of link-plates.

Main dimensions of all kinds of the tested link-plates are given in Fig. 1. Concerning with the varieties of the shapes, three values of K were selected, namely. $K_1=1.00$, $K_2=1.45$ and $K_3=1.93$, where K was the ratio of the cross section area CC to the cross section area AA. K_2 corrsponds to the standard link-plates.

The thickness of link-plates was 2.0 mm and the materials of them were Cr–Mo steel SCM 3 and special tool steel SKS 51.

The shapes of the link-plates, which were differently finished at their holes and which were shot-peened, were used by K_2. With finishing at holes, two types of perforators were used namely, single- and double-step punch. For each type, three methods of beveling were taken, namely, perforating methods, one-side-beveling method and both-side-beveling method. The material of the link-plates was S50C, carbon steel for mechanical structure.

T-OC centrifugal type shot-peening equipment produced by Nichu Co. Ltd., of the roter power of 5 HP the circumferential speed of 38 m/s and of 2900 r.p.m. was used. Five conditions were taken for shot-peening and, by adding the link-plates without shot-peening, totally six kinds of specimens were tested. The conditions for shot-peening are given in Table. 1. Speaking of the diameters of the shot, three kinds of steel bolls were used and their diameters were 1.0 mm, 0.5 mm and 0.3 mm.

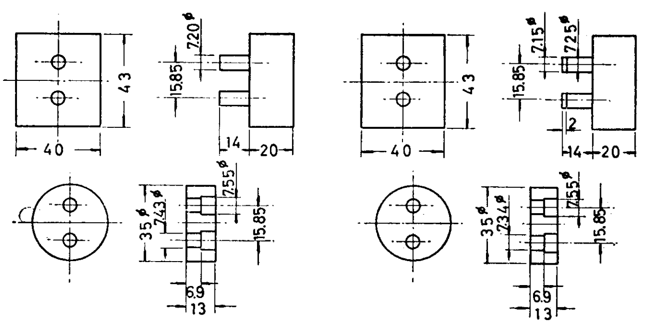
Table 1. The conditions for shot-peening.

Link-Plates	Shot's diameter (mm)	Peening time (min)	Shot speed (m/s)	Pass number of Shot-peening (×1)	Arc-height (mm)	Coverage (%)	Total weight of shot (kg)	Hardness H_{RA}
No. 1	—	—	—	—	—	—	—	75.6
No. 2	1.0	20	38	10	0.70	43.3	75	76.4
No. 3	0.5	10	38	5	0.43	69.3	75	76.8
No. 4	0.5	20	38	10	0.44	71.6	75	77.0
No. 5	0.5	30	38	15	0.45	74.0	75	77.2
No. 6	0.3	20	38	10	0.32	81.2	75	77.0

The peening time was 20 minutes for the shot with the diameter of 1.0 mm or of 0.3 mm and 10 minutes for the shot with the diameter of 0.5 mm. The material of the link-plates was S50C, carbon steel for mechanical structure. The shapes, the finishing at holes, the chemical components and the mechanical properties of the link-plates shot-peened followed JIS but the condition of heat treatment did not correspond to JIS.

For the influence of the shapes, both materials were heated to 850°C, austempered at 260°C for 20 minutes, and tempered at 200°C for 30 minutes. When it was concerned with the finishing at holes, they were heated to 850°C and austempered at 300°C for 20 minutes, and, as to the effect of shot-peening, they were quenched at 850°C and then austempered at 300°C for 20 minutes.

The dimensions of the perforators and the beveling tools used for various finishing conditions are given in Fig. 2 and 3, and the dimensions of the six kinds of holes are given in Fig. 4 in details.



Single-step punch Double-step punch

Fig. 2. Punching tools.

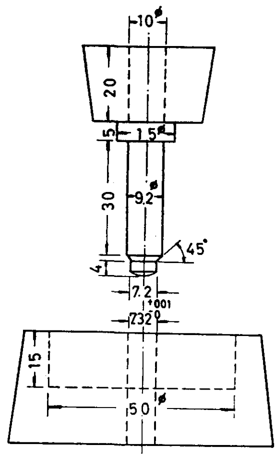


Fig. 3. Perforating tool.

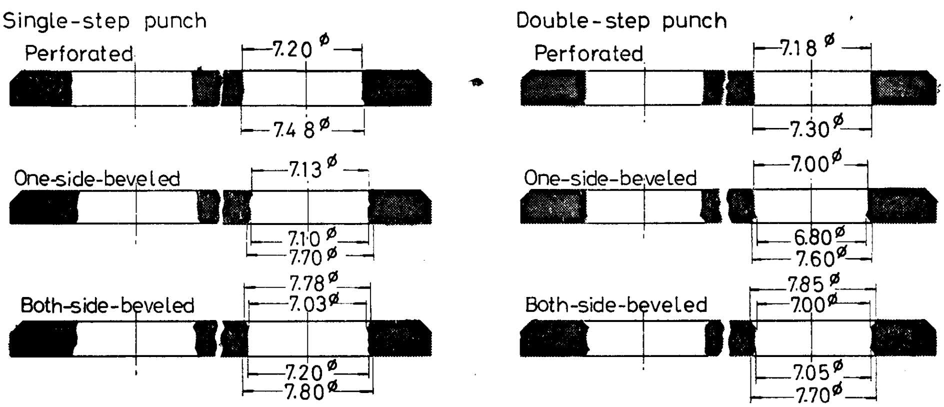


Fig. 4. Dimentions of the six kind of holes.

III. Methods of testing

For the fatigus tests, a jig that attaches link plate was produced as shown in Fig. 5, and link-plate was fastened by two pins piercing through the holes of it. For convenience, about 3 kg/mm² of minimum stress was applied initially. In the case of the specimens shot-peened, the repeated impact tests were done. In Fig. 6, the attaching situation of a specimen to the Matsumura's repeated impact tester is shown. Differing from the fatigue tests, one end of the jig that attaches specimen was fastened to the support of the tester and by penetrating a pin through the end, a link-plate was hung, and in addition, by using a tension block and pins, an impact face was formed.

During the tests, the impact energy was reduced gradually from the maximum impact energy of the tester's capacity in accordance with the situation of failure. In Fig. 7, the case of the Charpy's impact tester is shown. A Specimen was fastened between the hammer and the tension block by jig. Repeated impact loads were applied by swinging the hammer upward repeatedly, manually with the aid of a rotating handle. I needed so much effort that the test was done in the range of the number of repetitions were not more than 100.

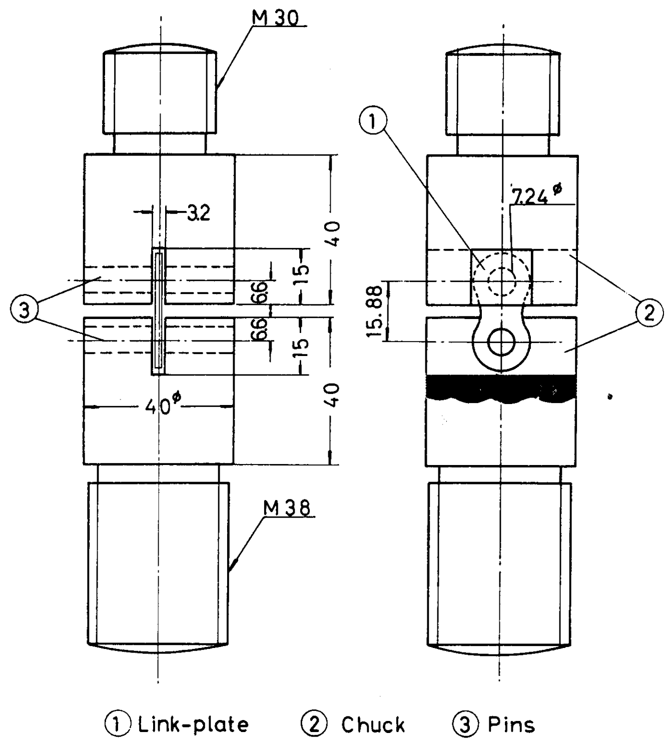


Fig. 5. Test link-plates and chucks for fatigue test.

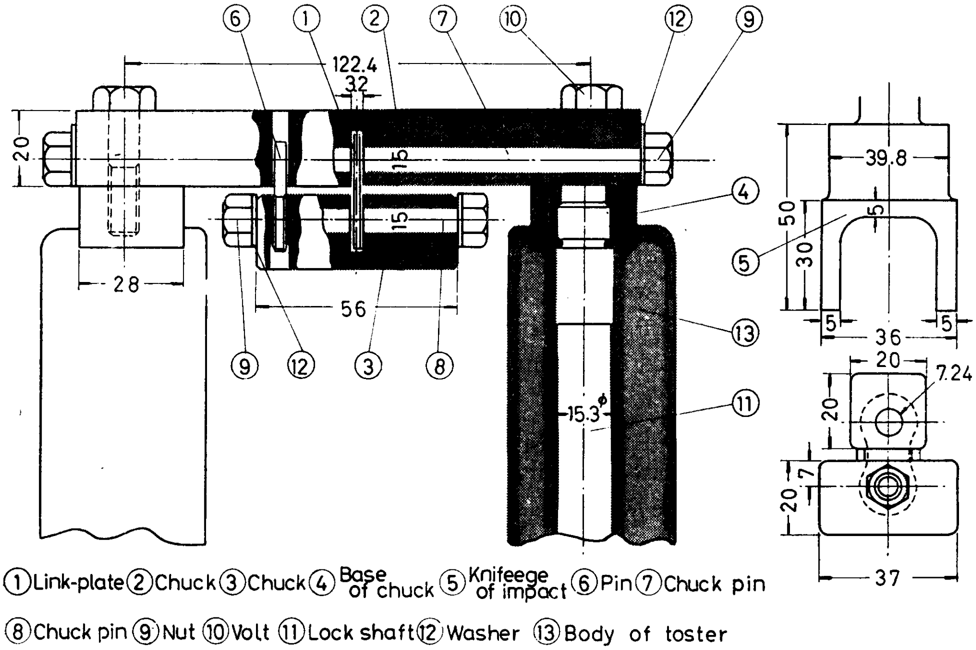


Fig. 6. Chucks for the Matsumura's repeated impact tester.

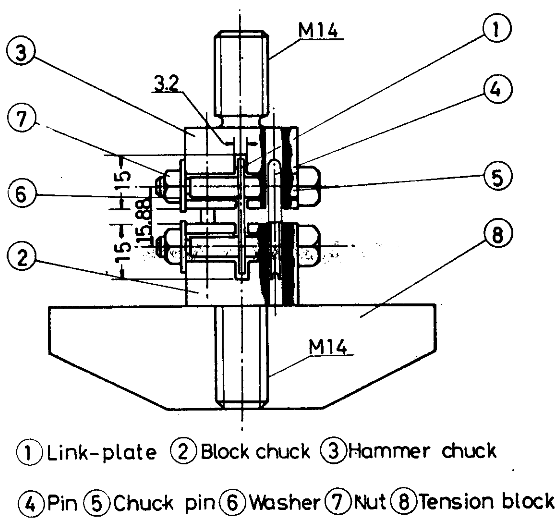


Fig. 7. Chucks for the Charpy's impact tester.

IV. Results of test

IV. 1. Fatigue strength

Test data for each kind of the link-plates were described as S-N diagrams.

In S-N diagrams, repeated stresses plotted on ordinates are twice the amplitudes and are the values obtained by dividing repeated loades by the area at the cross-section *AA* as shown in Fig. 1. The number of repetitions plotted on abscissa are the number of repetitions plotted in logarithmic scale, at which specimens break. First of all, it may be seen in Fig. 8 and 9, the shape K_3 with no contraction had a better endurance limit than the shapes K_2, K_3 regardless of materials of the link-plates. When the material was SCM3, the endurance limits were 13.7 kg/mm², 14.5 kg/mm² and 14.8 kg/mm², respectively, for K_1, K_2, and K_3. When the material was SKS 51, the tendency of increasing endurance limits was almost the same as that of SCM3.

Influence of six way of the finishing conditions of holes was as seen in Fig. 10, when the specimens perforated by single-step punches were concerned, the specimens both-side-beveling-type were the strongest and those of peforating-type were the weakest. If specimens perforated by double-step punches are concerned, the tendency remained the same, so far as the varieties of beveling conditions were considered as to the influence by the difference between the both punches, the specimens perforated by double-step punches showed higher strength than those

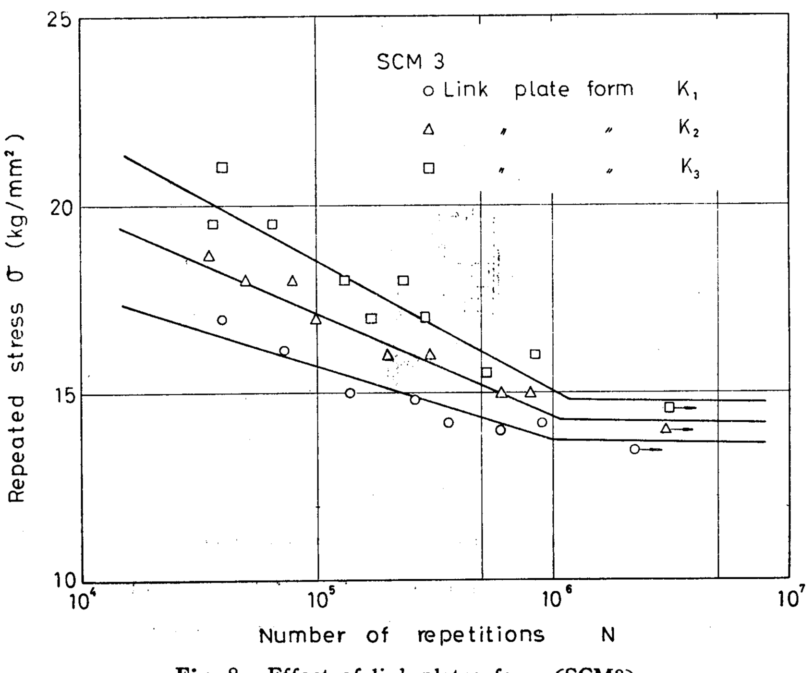


Fig. 8. Effect of link-plates form (SCM3).

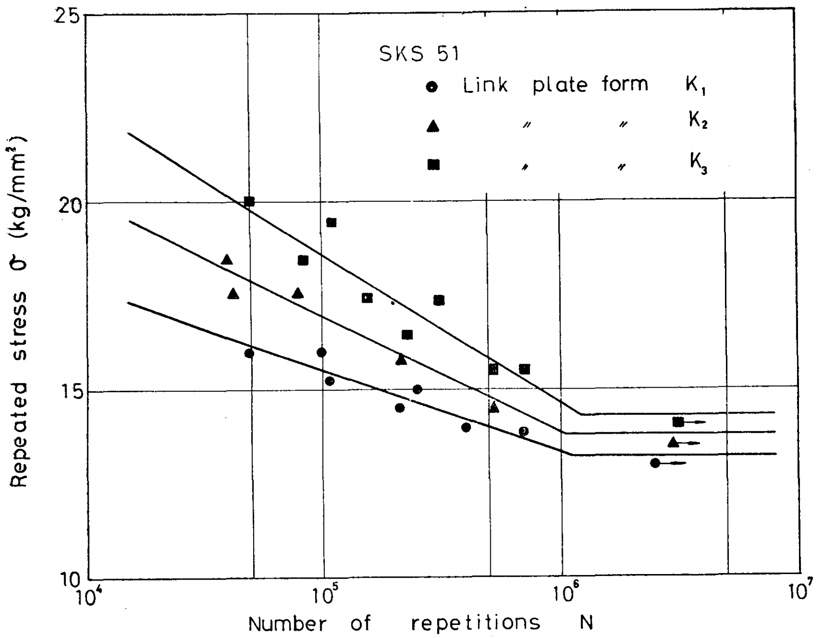


Fig. 9. Effect of link-plates form (SKS 51).

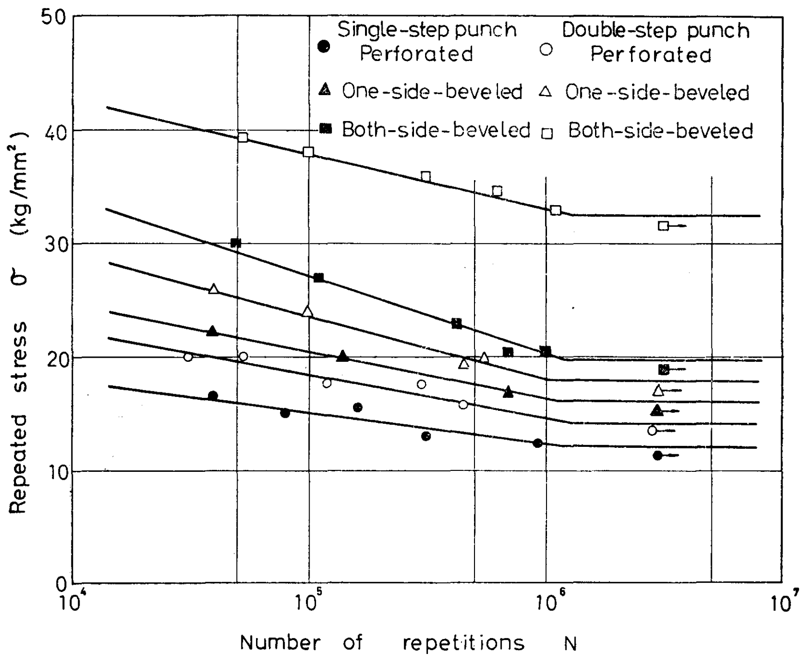


Fig. 10. Effect of the finishing conditions of holes in six way.

perforated by single-step punches. Especially, the specimens finished on both sides by double-step punches showed eminently high strength in comparison with the others.

In the cases of specimens that were shot-peened, by regarding the specimens with their shot's diameter 0.5 mm and with three different peening time, and by adding data for raw specimens to them, S-N diagrams were obtained as in Fig. 11. Secondly, in order to investigate the effects of changing the shot's diameter, S-N diagrams were obtained as in Fig. 12 by regarding the specimens with 20 minutes of peeing time and with three different sizes of shot, and by adding data for raw link-plates to them.

Looking into Fig. 11, it is seen that the endurance limit of the raw link-plates No. 1 that were not shot-peened was 10.5 kg/mm², while those of the specimens shot-peened, No. 3, 4, 5, were 14.5 kg/mm², 14.0 kg/mm² and 13.5 kg/mm², respectively.

Therefore, to refer to the influence by peening-time, when the shot with its diameter 0.5 mm was used, 10 minutes of peening-time is the most adequate. If the time is longer than 10 minutes, the tendency is seen that the fatigue strength decreases as the time increases.

This may show that, when the shot's diameter is constant, the exceeding time causes the compressed residual stresses on the surfaces of specimens to grow exceeded, and then the phenomenon of exceeded shot-peening is given rise to weaken the fatigue stresses.

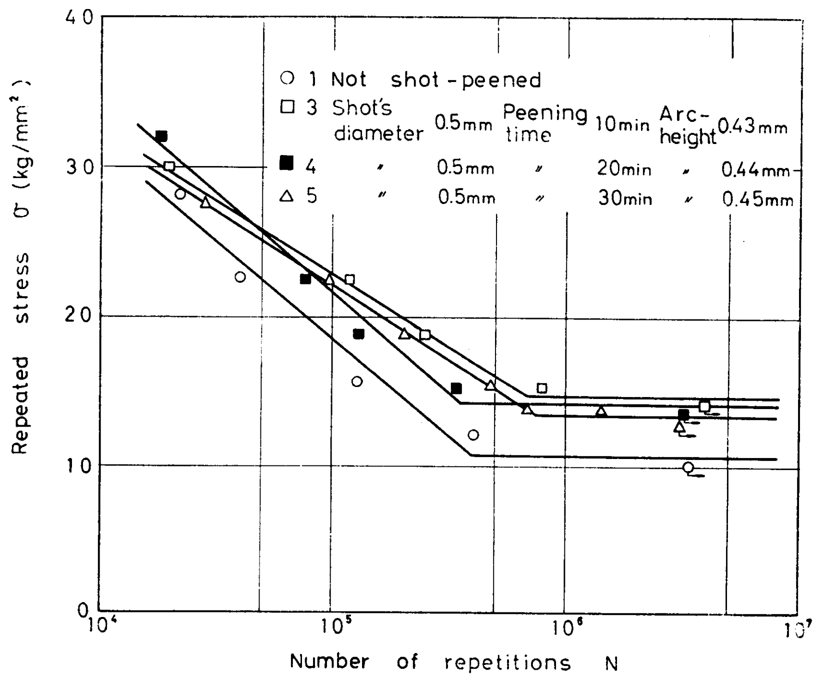


Fig. 11. Effect of peening time (Haigh's).

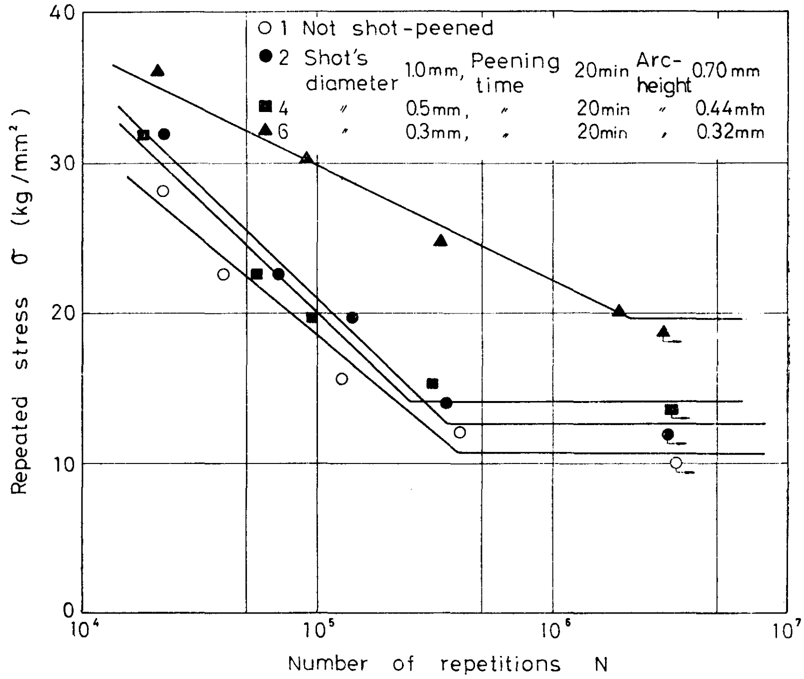


Fig. 12. Effect of shot-diameter (Haigh's).

Looking into Fig. 12, it is seen that the endurance limit of the specimens No. 6 was 19.5 kg/mm² and was higher that those of the other two kinds that were shot-peened. This may be caused by the differences of the shot-diameter and the magnitudes of compressed residual stresses giving influence to the fatigue strength. Since the endurance limit of the specimens that were shot-peened with shot-diameter 1.0 mm was 10 % and 35 %, lower than those of the specimens No. 4 and 6, respectively, it may be said that the tendency of over-peening [4] lowers the fatigue strength.

IV. 2. Repeated impact strength of link-plates shot-peened

Here, the results of repeated impact tests, done with the link-plates shot-peened, will be shown.

In accordance with the fatigue tests for link-plates shot-peened, the test results were arranged, by adding three types of the specimens, No. 3, 4, 5 and raw specimens that were not shot-peened together and by regarding them as a group, and also by regarding the specimens, No. 2, 4, 6 and 1 as a group.

In Fig. 13, 14, 15 and 16, the above results are described as the relations between the impact energies and the number of repetitions. The impact energies plotted on ordinates, in the case of the relation $W=wl \sin \alpha$, where w is the weight of the hammer, l is the distance from the center of the rotating axis to the center of gravity and α is the lift angle.

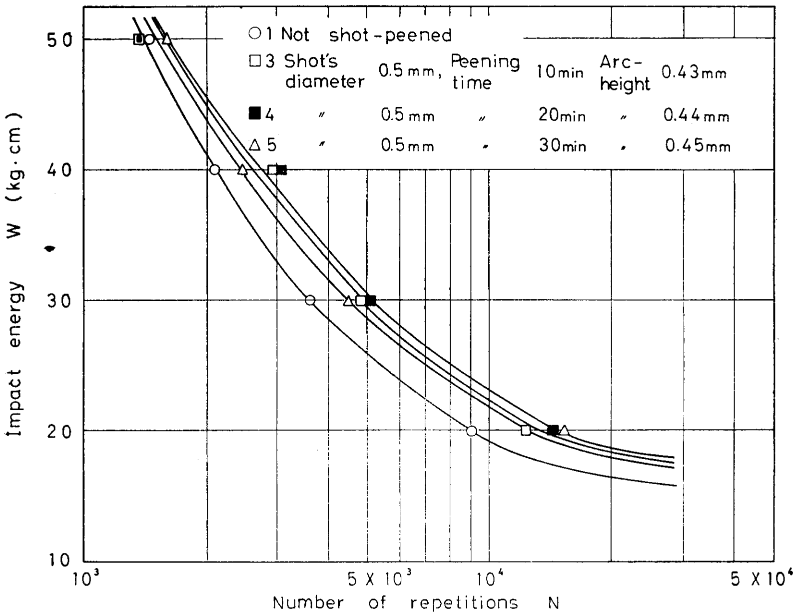


Fig. 13. Effect of peening time (Matsumura's).

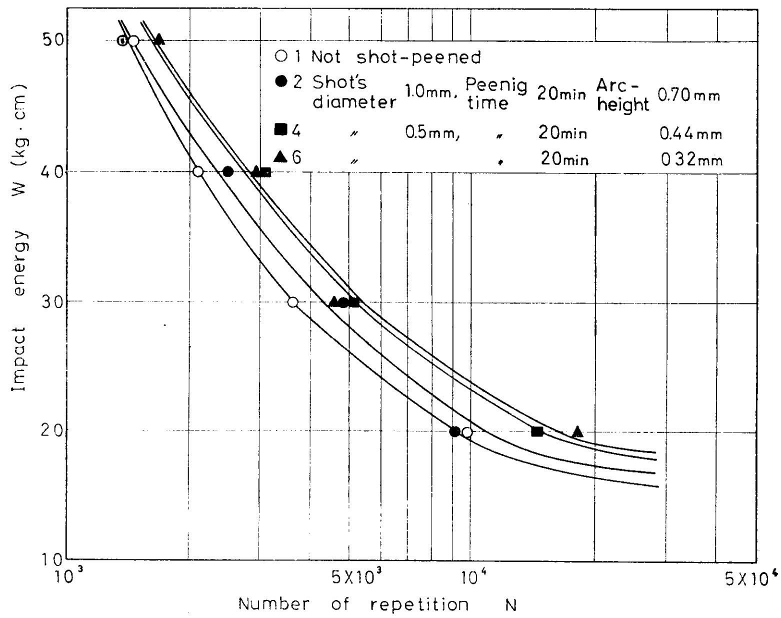


Fig. 14. Effect of shot-diameter (Matsumura's).

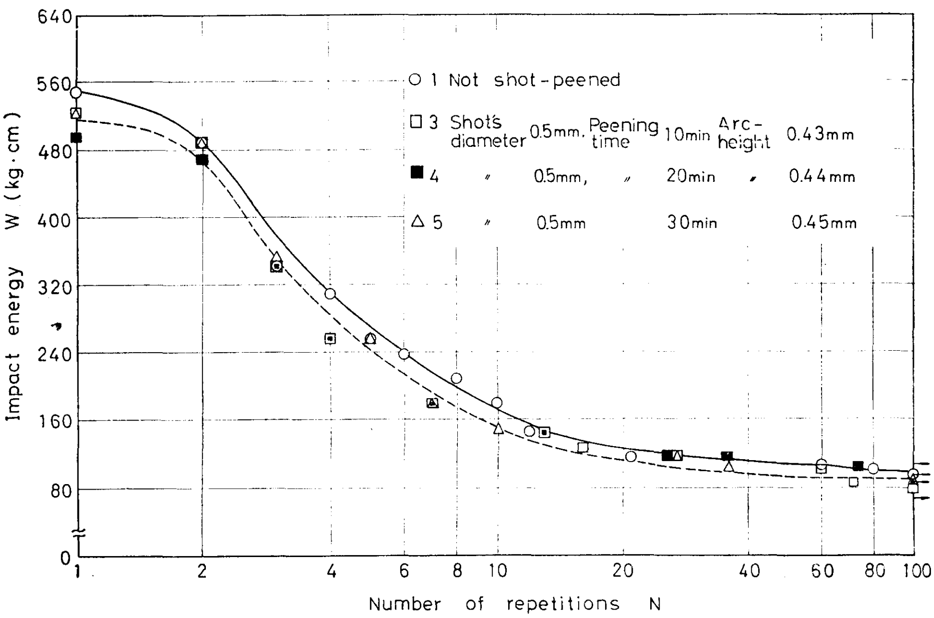


Fig. 15. Effect of peening time (Charpy's).

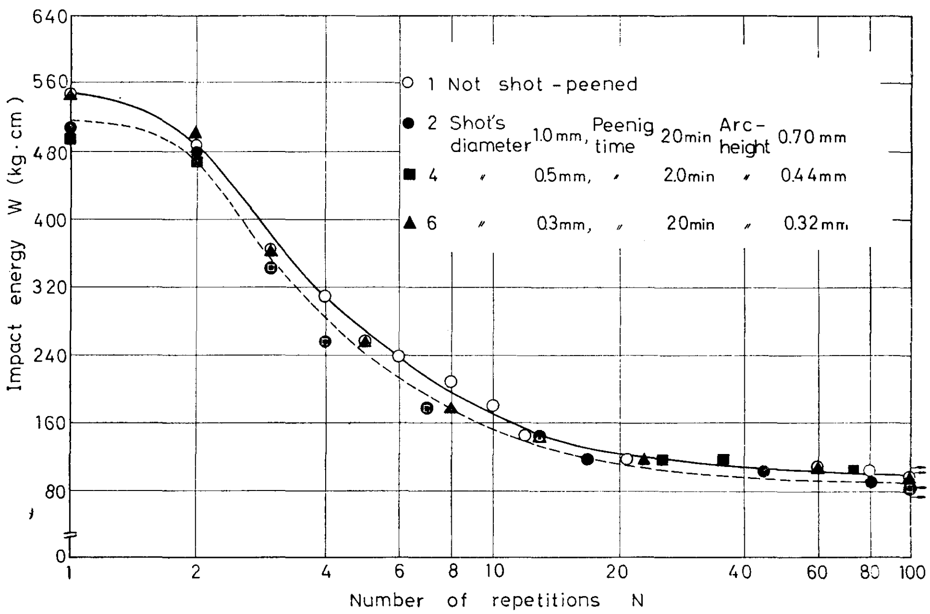


Fig. 16. Effect of shot-diameter (Charpy's).

In the case of the Charpy's impact tester, when the specimens are broken at the first strike, it is a simple impact test. In the above case, the energies absorbed at the breaking were taken as the energies on ordinates.

The number of repetitions plotted on abscissae are in the logarithmic scales of the repeated times at the breaking. The effects of the peening time obtained by using the Matsumura's repeated impact tester were very eminent for the specimens No. 3, 4, and 5, except for those that were not shot-peened, and it is seen that the specimens No. 5, 4, and 3 were the strongest, the second strongest and the weakest respectively, when they were compared by their number of repetitions at ultimate impact energies. When the strength obtained from the results of the fatigue tests was considered, the differences between the strength of the specimens No. 6 and those of the other four kinds that were not shot-peened were evident to some extent, but, as to the other four kinds of raw specimens that were not shot-peened, although the specimen No. 2 showed a little lower value in their strength, the differences were not evident.

What may be said about the results by the Charpy's impact tester as a whole is that shot-peening hardly give significant effects, and that rather the specimens without shot-peening showed a little higher strength. Since little significance in shot-peening was seen in the sense of strength, the results for the raw specimens were described by a full line, while those for the specimens shot-peened were described by a dotted line in Fig. 15 and 16.

It is supposed that the reason why the specimens shot-peened had a little lower strength as shown above is that the residual stresses caused by shot-peening were almost eliminated by repeatedly applied high loads and the strength lowered by work-hardening on the contrary.

V. Strength coefficients and endurance ratios of shot-peened link-plates

As to the shot-peened specimens static tension tests were done to get tensile strength.

Static tension tests were done also for the link-plates materials and strength coefficients of the link-plates were given. The endurance ratios were calculated from endurance limit and the tensile strength for the link-plates. The results are in Table 2.

In the table, the notation σ_B stands for the tensile strength of the link-plates and σ_B' the tensile strength of the link-plates materials. To each link-plate's strength to static tensile loads, the effect of shot-peening was not obvious.

Therefore, it may be said that shot-peening didn't give any significant effects on static tensile strength.

Table 2. Strength coefficients and endurance ratios of shot-peened link-plates.

Link-plates	Strength Coefficients (σ_B'/σ_B)	Tensile strength σ_B(kg/mm^2)	Endurance ratio (σ_v/σ_B)
No. 1	1.32	132.2	0.079
No. 2	1.22	137.3	0.091
No. 3	1.31	137.0	0.106
No. 4	1.25	136.0	0.103
No. 5	1.27	137.5	0.098
No. 6	1.30	136.8	0.141

VI. Peening conditions and fatigue limit ratios

It was noted in IV. 1 that the fatigue strength depending on the shot-peening time. Based on it, fatigue limit ratios were defined as the ratios of the fatigue limits of the shot-peened link-plates to those of the link-plates without peening, and how the differences of peening time influenced the fatigue strength was studied. In Fig. 17, the specimens with the same shot-diameter and with different peening time and Pass numbers of shot-peening are compared and it is seen that the strength changed almost linearly. In Fig. 18, the influences, of shot-diameter and of arc-height were shown for the specimens No. 2, 4, and 6.

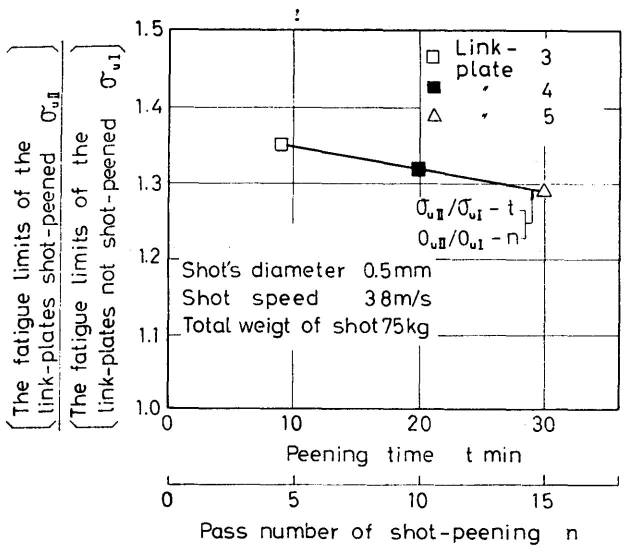


Fig. 17. Relations of peening time, Pass number of shot-peening and fatigue ratios.

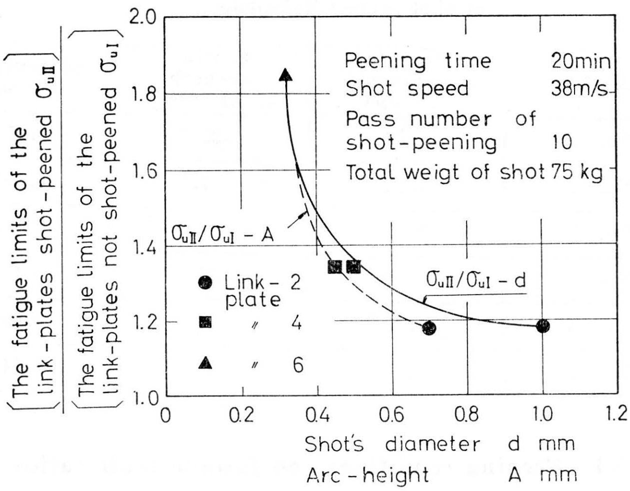
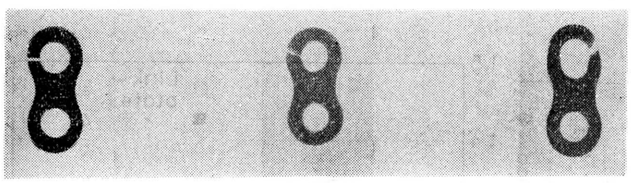


Fig. 18. Relations of shot-diameter, arc-height and fatigue ratios.

VII. Situations of fracture surface

The Situations of fracture surface in the fatigue tests and the repeated impact tests are shown for the specimens No. 6 that were shot-peened.



(a)	(b)	(c)
Fatigue failured (Haigh's)	Repeatead impact broken (Matsumara's)	Repeated impact broken (Charpy's)
Repeated stress 20.5kg/mm^2	Impact energy 20kg·cm	Impact energy 116kg·cm
Number of repetitions 1.90×10^6	Number of repetitions 1.815×10^4	Number of repetitions 23

Fig. 19. Situation of fracture surface.

In the case of the fatigue tests, it can be seen that the fracture occurred at *AA* in Fig. 1 where comparatively high stresses concentrated, or at *BB*.

In the case of the repeated impact tests by the Matsumura's repeated impact tester, the above cross sections were rather strengthened because of plastic deformation and it may be supposed that the breaking positions moved a little aside. In the case of Charpy's impact tester, it is seen that the positions moved much further because of the plastic deformation.

VIII. Conclusions

The important items obtained in this study are listed up as follows.

1. As to the influences on the fatigue strength by the differences of shapes, the larger the width at central contraction is, the higher the fatigue strength is.

2. As to the differences in methods of finishing for holes, link-plates perforated by double-step punches are stronger than those perforated by single-step punches.

As to the differences in beveling methods, link-plates beveled on both sides are stronger than those simply perforated. Especially, link-plates beveled on both sides by double-step punches have exceedingly high fatigue strength, compared with the others.

3. Shot-peening gives significant influence to fatigue strength. Especially, the specimens No. 6 were better in strength than the other four kinds that were shot-peened, and showed 85 % higher strength than raw link-plates.

4. The shot-peening effects in repeated impact tests by the Matsumura's repeated impact tester were not as significant as in fatigue tests.

However, the effects become more important, the smaller the repeated impact loads become. When it was concerned with the specimens No. 6 that showed excellency in the fatigue tests and when the impact energy was 20 kg·cm, the number of repetitions of them until they broke was about twice the same as those of raw link-plates.

There is not short-peening effect in the high speed repeated impact tests by the Charpy's impact tester, but link-plates that are not shot-peened are a little better in their strength.

5. There is hardly any significant influence of shot-peening to static strength. No clear significance was gained.

6. From what have been mentioned above, so far as the strength is concerned, link-plates with no contraction at their centers should be used in chains.

As whole chains, however, accordance with the outer link-plates and the total weight should be taken into consideration. Thus, it is very difficult to decide the shapes.

On the other hand, for standard link-plates that are finished at their holes and shot-peened, it may be supposed that the fatigue strength will be improved.

Acknowledgement

I wish to express many thanks to Prof. Masao Mizuno; Faculty of Engineering, Keio Univ. and Mr. Yasuo Funabashi; Takasago Chain Co. Ltd., for supporting me to this study from the begining to the end.

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