EFFECT OF SHOT PEENING ON FATIGUE STRENGTH OF SMALL SPRING WIRE AND COIL SPRINGS

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ABSTRACT

In the present works, the fatigue characteristics of small springs, of which the diameter is ranged from 0.8mm to 4.0mm, was studied, and for comparisons, the straight wire was also tested by a miniature rotary bending fatigue testing machine which was newly designed. Material of specimen was music wire. In order to strengthen, specimens were shot peened under various conditions. Although an optimum arc-height for usual shot peening of general coil spring is about 0.3mmA, that for small spring, the diameter of which is 2.0mm, for example, was 0.05 0.1mmA, and the improvement of fatigue strength exceeded 40% over non-peened specimen.

KEYWORDS

Shot peening; coil spring; fatigue strength.

INTRODUCTION

The coil spring, of which the diameter is over about 4.0mm, was usually strengthened by shot peening. However, it has not been usual for small spring, of which the diameter is under 4 mm, to be shot peened because of too much severe intensity. In recent years, the design stress required for small spring, of which the diameter is ranged from 0.8mm to 4.0mm, has been more severe, and the demand for the improvement of fatigue strength has been increasing.

Therefore, the Society of Spring Research of Japan has organized a research group of shot peening for small coil spring in March 1978. The research group has chosen music wire and has investigated the optimum shot peening condition. The fatigue tests for coil spring were carried out with repeated compressive testing machine, and fatigue tests for straight wire were done with rotary bending fatigue testing machine.

MATERIAL

Dimension and Mechanical Properties of specimen

The material in the tests is music wire (SWPB). The diameters of the wires tested and mechanical properties are shown in Table 1.

TABLE 1 Mechanical Properties of Music Wire Tested

Wire diameter mm	Conditions of heat treatment	Ultimate strength σ_B kgf/mm^2	Elastic limit $\sigma_{0.02}$ kgf/mm^2	Yield point $\sigma_{0.2}$ kgf/mm^2	Young's modulus E kgf/mm^2
0.8	300°C, 30min	235	188	213	22000
1.0	300°C, 30min	231	182	213	21200
2.0	350°C, 30min	201	155	175	21200
3.0	350°C, 30min	197	154	174	20900
4.0	350°C, 30min	184	142	157	20800

Specimens

Coil springs for repeated compressive fatigue tests. After wires were straightened, they were formed into coil springs which have the dimensions shown in Table 2, and they were heat treated at low temperature, as specified in Table 3. Furthermore, three-fourth of one turn of coil spring was ground.

Test pieces for rotary bending fatigue tests. After straightening, the wires were similarly heat treated at low temperature, as specified in Table 3. Then, they were sheared into the prescribed length to use for test specimens. Since the fatigue testing machines were different according to the diameter of spring wire, the total length of the specimen was determined as 400mm for the wire of less than 2mm diameter and as 500mm for that of over 3mm.

TABLE 2 Size of Coil Spring Specimens

Items \ Wire diameter, mm	0.8	1.0	2.0	3.0	4.0
Effective number of turns	4.5	4.5	4.5	4.5	4.5
Total number of turns	6.5	6.5	6.5	6.5	6.5
Mean diameter of coil, mm	8.0	10.0	18.5	25.0	28.0
Free height, mm	28.0	33.0	47.0	55.0	60.0
Stiffness, kgf/mm	0.128	0.228	0.576	1.18	2.66
Height, mm (in solid state)	5.2	6.5	13	19.5	26
Load, kgf (in solid state)	4.15	6.04	19.6	42	90
Stress, kgf/mm^2 (in solid state)	189	176	133	116	122

TABLE 3 Conditions of Low Temperature Heat Treatment after straightening or Coil Forming

Wire diameter, mm	Temperature, heating time	
0.8, 1.0	300°C,	30min
2.0, 3.0, 4.0	300°C,	30min

Surface Preparation of Test Piece

In shot peening processing, both arc-height and coverage, which are dependent on size and mass, hardness, velocity and weight of shot, are usually specified. However, even if the arc-height and coverage are the same, the same effect for the fatigue life would not be necessarily obtained when the factors stated above, are different. In these series of tests, various shots, of which the nominal diameters were 0.7mm, 0.5mm, 0.3mm and 0.2mm, were used, as shown in Table 4. The Table 4 also indicates the arc-height of shot peening. In case of shot peening of the wire of less than 2mm diameter, of which the length is 400mm, the central part of about 250mm, and in case of that of over 3mm diameter, the central part of about 300mm were shot peened uniformly. There are eight combinations of shot peening conditions, and the number of test pieces of each combination is 20 both in case of coil spring and straight wire. Two pieces among them were used for hardness, surface roughness, microscopic structure and residual stress measurement. On the other hand, 30 test pieces which were the same wire diameter were tested as raw material. In this case, two pieces were used for the same object. After shot peening processing, coil spring specimens were heat treated at low temperature (220°C, 30min), but straight specimens for rotary bending fatigue test were not heat treated, because the condition is different.

TABLE 4 Conditions of Surface Preperation

Nominal diameter of shot, mm	Range of size of shot, mm	Arc-height mmA	Coverage %
0.7*	1.00～0.59	0.35, 0.30	
0.5	0.71～0.35	0.30, 0.25	80～90
0.3	0.50～0.177	0.25, 0.15	
0.2	0.35～0.125	0.10. 0.05	

*Instead of shot of 0.7mm diameter, the one, of which the nominal diameter is 0.04mm is used for the specimens of 0.8mm diameter and specified arc- height is 0.03mmA or 0.05mmA.

Fatigue Test

Repeated compressive fatigue testing machine. Shimazu's repeated compression testing machine was used. Inside the frame of circular shape are attached radially 16 test

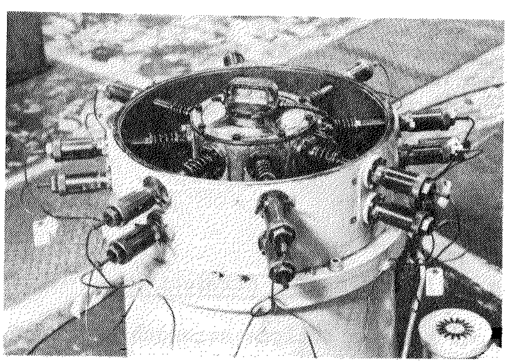

Fig. 1. Repeated compressive fatigue testing machine

coil springs, and these specimens are compressed in turn, by rotating cam which is equipped at the central position. The speed of revolution of the cam shaft is 1000 rev/ min. Figure 1 is a photograph of this machine.

Rotary bending fatigue testing machine. In Japan, Haigh Robertson's or Nakamura's fatigue testing machine is usually employed for the rotary bending fatigue test of wire. However, when the wire diameter of specimens becomes less than 2mm, it is difficult to use these machines. Therefore, a miniature rotary bending fatigue testing machine that are newly designed for small wire, of which the diameter is less than 2mm, were used. Figure 2 shows the photograph of this machine.

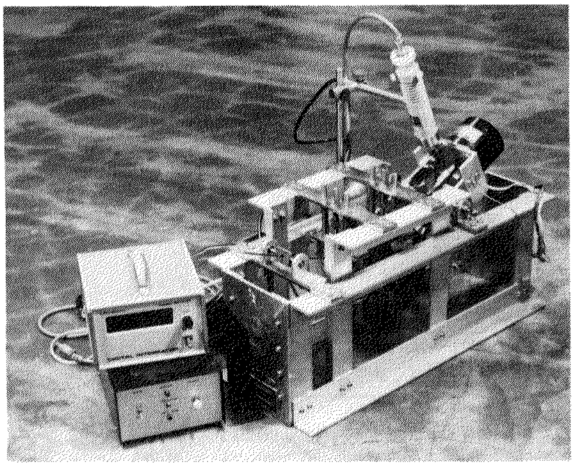

Fig. 2. Miniature rotary bending fatigue testing machine

Measurement of Residual Stress

The residual stress in the axial direction were measured by X-ray diffraction. In order to obtain the distribution along the direction of depth, new surface was exposed by successive chemical polishing. The surface layer was removed by about 0.01mm in one cycle of chemical polishing.

Size Change and surface roughness

The change of surface roughness due to shot peening were measured by Kosaka's profilometer and the change of coil spring size i.e. free height and coil outside diameter also measured even though it were slight.

EXPERIMENTAL RESULTS

Results of Rotary Bending Fatigue Tests of Straight Wire.

Figure 3 shows the relations between fatigue strength and arc-height. As shown in the Table 1, the smaller the diameter is, the higher the ultimate strength becomes, similarly the fatigue strength also increases. It can be seen from the Fig. 3 that the optimum condition which gives the maximum increase of fatigue strength exists

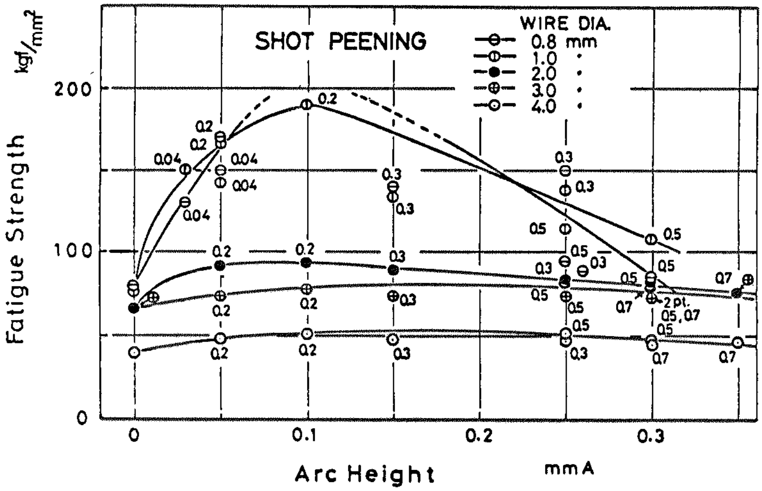

Fig. 3. Fatigue strength of straight wire specimen vs. arc-height in shot peening for various wire diameters and shot sizes

and the optimum value of arc-height becomes lower in case of small wire diameter, comparing with usual objects. In Fig. 3, the values on the ordinate which means zero arc-height are those of non-peening.

Results of Fatigue Test of Coil Springs.

In case of fatigue test of coil springs, specimens were attached to fatigue testing machine, under a mean shearing stress of 60kgf/mm² (588MPa), and repeated compressive

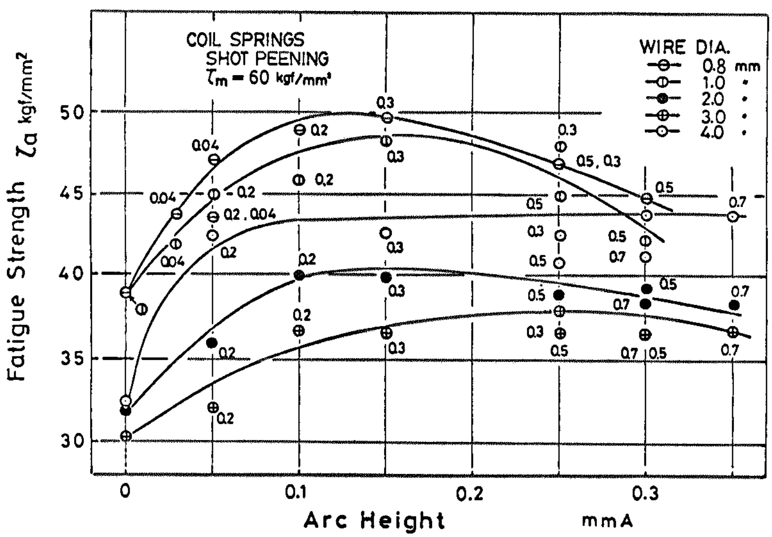

Fig. 4. Fatigue strength of coil spring vs. arc-height in shot peening for various wire diameters and shot sizes

load of predetermined amplitude were applied. When the specimen did not make failure after the repetition of $5x10^6$, the test was discontinued, In Fig. 4, the relations between the increase of fatigue strength and arc-height are shown. Different from in case of straight wire, the coil spring of wire diameter of 4.0mm that is not shot peened has shown the higher fatigue strength than that of wire diameter 2.0mm and 3.0mm, and the tendency is the same in shot peened ones also. At present, the reason is not clear. In this case also, the optimum conditions exist, and comparatively good agreement of the arc-height was seen between wire and coil spring tests.

Distribution of Residual Stress

As is the case of plate specimen, the distribution of residual compressive stress, in case of wire, showed peak absolute value at some depth from the surface, then, lowered the absolute value as the depth increased and became zero at some depth. The members of the research group called this point "crossing point". It was the same that it changed into tensile residual stress after that. In Fig. 5 are shown the values of residual compressive stress at surface layer, the peak values and the depth of peak value and crossing point, corresponding to the combinations of size of

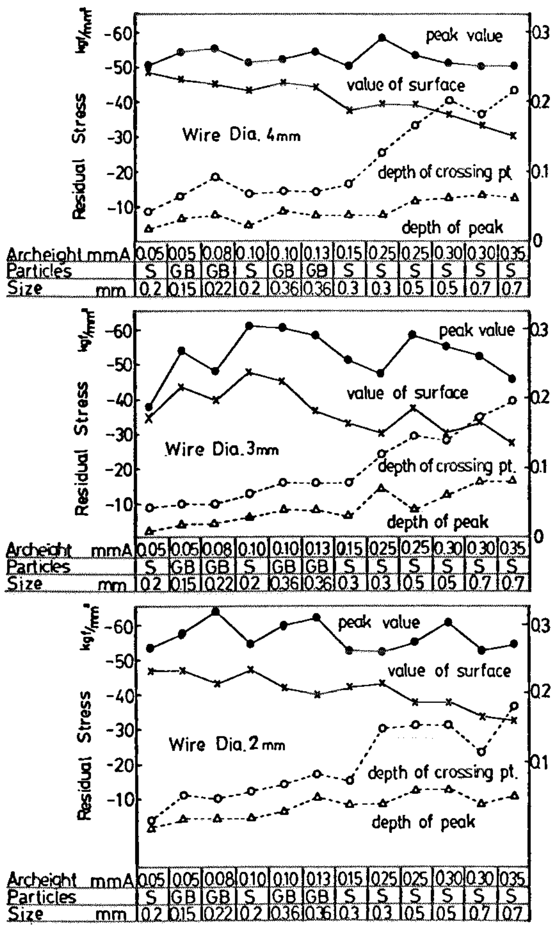

Fig. 5. Values of residual stress and those of depth for various conditions

particle and arc-height. It was not recognized discrepancy between plate and wire. The capitals S and GB written in the Fig. 5 mean shot and glass beads respectively.

Surface Roughness

In Fig. 6 are shown the relations between the arc-height and the surface roughness taking wire diameters as parameters. In the Fig. 6, the values which lie on the zero value of abscissa, are those of non-peened. As is seen, the surface roughness increased as arc-height becomes higher.

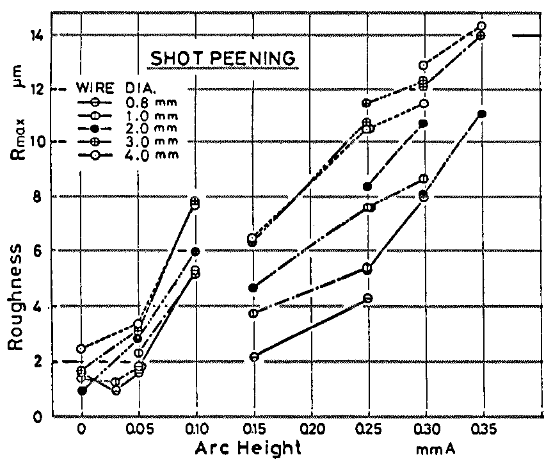

Fig. 6. Change of surface roughness vs. arc-height due to shot peening

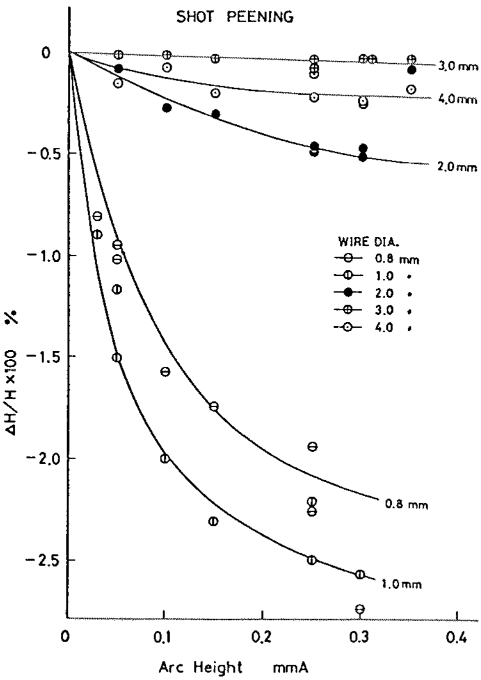

Fig. 7. Change of free height of coil. spring due to shot peening

Change of Shape of Coil Spring

In Fig. 7 are shown the relations between changes of free height and arc-height of shot peening. The free height is lowered, in generally, and it is remarkable in case of small wire diameter. In Fig. 8 are shown similarly the changes of the outside diameter of spring coil, and it shows the tendency of enlarging of the value, and is also remarkable in case of smaller diameter. At any rate, the absolute value was small, and the maximum value of standard deviation in case of free height of 27mm and wire diameterof 0.8mm, was 0.267mm. However, it can not be negligible when applied to precision machines and appratuses.

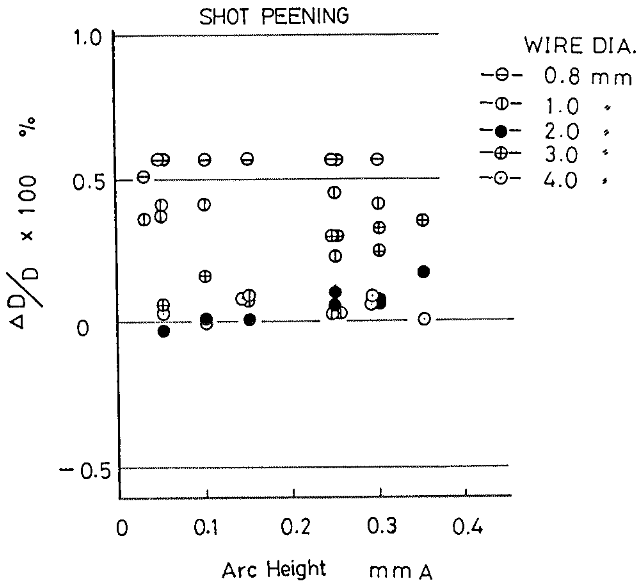

Fig. 8. Change of outside diameter of coil spring due to shot peening

DISCUSSION

It means the insufficiency of the miniature rotary bending fatigue testing machine that the test results of around the peak value for the straight wire specimen of 0.8mm diameter are shown by dotted line in Fig. 3. That is to say, since the deflection of the wire specimen became very large and the static shape of the deflection was not kept in the running state, the exact value of the stress could not calculated. In such a case of wire of particularly small diameter, it will be appropriate to shorten the distance between two loading points. Fig. 9 shows the relations between the ratio of fatigue strength in each arc-height, which expressed as a percentage of the maximum fatigue strength under optimum condition obtained in the Fig. 3, and the

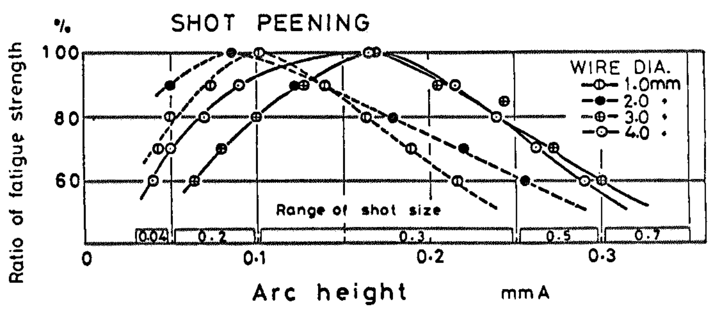

Fig. 9. Ratio of fatigue strength expressed as a percentage of the maximum value under optimum peening condition vs. arc-height

arc-height. It is able to read the values of upper and lower limits of arc-height that give the fatigue strength not less than at least 80% of the maximum value under the optimum condition. The similar figure will be obtained for coil springs, but the range of upper and lower limits of arc-height becomes extremely broad. In this case, It is necessary to take the deformation of the shape into account. Although the optimum values of arc-height both in cases of wires and coil springs show a comparatively good agreement, one of the reasons why they do not necessarily show complete agreement will be the difference of applied stress state.

CONCLUSIONS

Fatigue tests with coil springs, of which the diameters of the wire are respectively 4.0mm, 3.0mm, 2.0mm, 1.0mm and 0.8mm, and with straight wires of the same diameters, which were all strengthened by shot peening, were done and the followings were obtained.

(1) In shot peening processing, the optimum combination of size of shot and arc-height exists, and it moves to lower peening intensity side as the diameter of wire becomes smaller.

(2) The optimum values of arc-height both in cases of fatigue test of wires and coil springs showed a comparatively good agreement.

(3) The distribution of residual compressive stress along the depth in case of wire, was similar as that of plate and it was not recognized any dicrepancy.

(4) Surface roughness increases as arc-height became higher.

(5) In general, the free height of coil spring was lowered and the outside diameter was enlarged due to shot peening. It was more remarkable in case of small spring, but the absolute value is small. However, it is necessary to take the deformation of spring shape into consideration, provided that it were applied for precision machines and apparatuses.

ACKNOWLEDGEMENTS

In March of 1978, Research Group of Shot Peening of Small Coil Springs had been organized by Society of Spring Research of Japan, gathering 24 spring manufacturing companies and 3 public organs (30 members), and it is still continued at present. This paper is a part of the research. The chairman would like to acknowledge sincerely all the members for their earnest co-operation and endeavour.