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# High Sag Resistance Spring Wire for Automotive Suspension

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ABSTRACT

In recent years, efforts have been undertaken to increase the stress load on spring materials and to decrease wire diameter in order to reduce weight. However, progress has been slow due to the resulting increase in spring sag. This report describes the characteristics of steel wire subjected to a new strain method. After quenching and tempering, while the wire is still warm, strain is imposed on the wire to improve its sag resistance. Results show that sagging in springs made of this wire is approximately one half that of springs made of conventionally quenched and tempered wire of the same strength. Moreover, strain-imposed wire can be quenched and tempered to a lower strength than, yet have the same sag resistance as, extremely high-strength conventional wire. As a result, problems encountered when high strength material is used to improve sag resistance -- such as damaged cutting tools and decreased shot peening effect -- can be avoided. After practical application, the fatigue life of this wire has been confirmed to be sufficient for commercial use.

AS PART OF THE RECENT TREND towards lighter car components, the reduced weight suspension coil spring has been awaited with great interest. However, any weight reduction also results in a higher load stress on the springs. Such higher stress presents the problem of increased sagging of the springs, and, thus, to a decrease in the height of the car body in the course of its use. Therefore, in order to improve the sag resistance, spring manufacturers have been obliged to include such extra processes as hot-setting in producing the springs.

This situation clearly demanded the development of a new steel wire for the coil spring which possesses high sag resistance, even under severe stress conditions.

Regarding methods to improve the sag resistance of steel wire, strengthening--raising the hardness of steel wire(1)*, or adding alloying elements such as V, Cb or Mo (2)(3) have been examined. In the case of the former method, however, the steel ductility decreases, resulting in limitations in manufacturing wires or forming coil springs. In the case of latter method, costs rise due to the addition of expensive alloying elements.

Based on this background, we have studied how to produce a high sag resistance spring wire with Si-Cr steel (SAE 9254). The method we developed included not only the conventional quenching and tempering treatment, but also techniques imposing strain on the wire after tempering.

Here, we report the results of examinations of the properties of the strain-imposed steel wire used for cold-formed suspension coil spring, comparing them with steel wire made through only quenching and tempering.

## PREPARATION

The chemical composition of SAE 9254 steel used in our test is shown in Table 1, and the manufacturing processes are shown in Figure 1.

Two kinds of steel wires were produced with hot-rolled rod 11.0mm in diameter; one was drawn to 9.5mm in diameter after having been descaled by pickling, and then tempered and quenched. The other was produced, in addition to the former processes, through strain-imposing at warm temperatures.

Regarding the method of imposing strain on the wire, we examined several. Here, we report the case of the cyclic bending method. The strength of the steel wire was adjusted by changing the tempering temperature; the tensile strength was 1670 - 2060MPa.

*Numbers in parentheses designate References at end of paper.

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Table 1 - Chemical Composition

wt%

| Material | C | Si | Mn | P | S | Cr |
|---|---|---|---|---|---|---|
| SAE9254 | 0.56 | 1.37 | 0.70 | 0.013 | 0.007 | 0.59 |

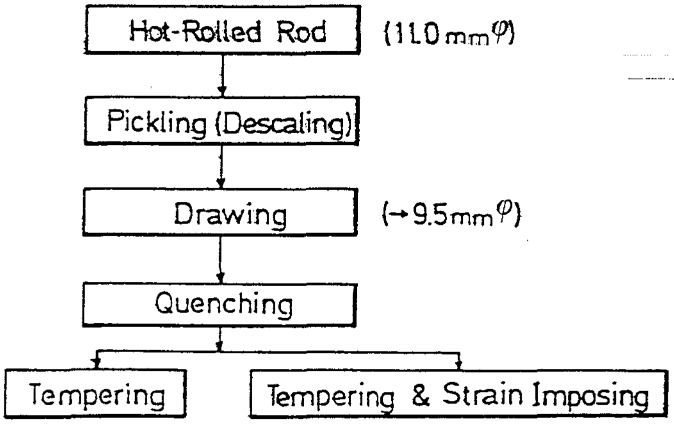



Fig. 1 - Manufacturing Processes

TEST OF STEEL WIRES

STRAIN-IMPOSING AND MECHANICAL PROPERTIES - In order to study the influence of strain-imposing on the steel wire, we measured the mechanical properties of steel wires which had been subjected to varying degrees of strain and then annealed at 623°K (662°F) for 30 minutes. Figure 2 shows, as an example, the mechanical properties of steel wire with tensile strength of 1940MPa which had been treated by cyclic bending at warm temperatures.

According to this figure, in spite of the imposed strain, the values of ductility factors elongation and reduction of area show very little decrease, and tensile strength $\sigma_B$ and torsion stress $\tau_{MAX}$ do not change much either. On the other hand, yield point (0.2% proof strength) $\sigma_{0.2}$ and torsion yield point $\tau_{0.3}$ show significant increase as the value of strain increases. Thus, $\sigma_{0.2}/\sigma_B$ and $\tau_{0.3}/\tau_{MAX}$ increase to 97% or greater, while they are approximately 93% if no strain is imposed.

CHARACTERISTICS OF LOW-TEMPERATURE ANNEALING OF THE STRAIN-IMPOSED STEEL WIRE - In order to study the influence of low-temperature annealing after forming the spring, we measured the mechanical properties of the strain-imposed steel wire after keeping it at 523°K (482°F) - 673°K (752°F) for 30 minutes. Figure 3 shows, as an

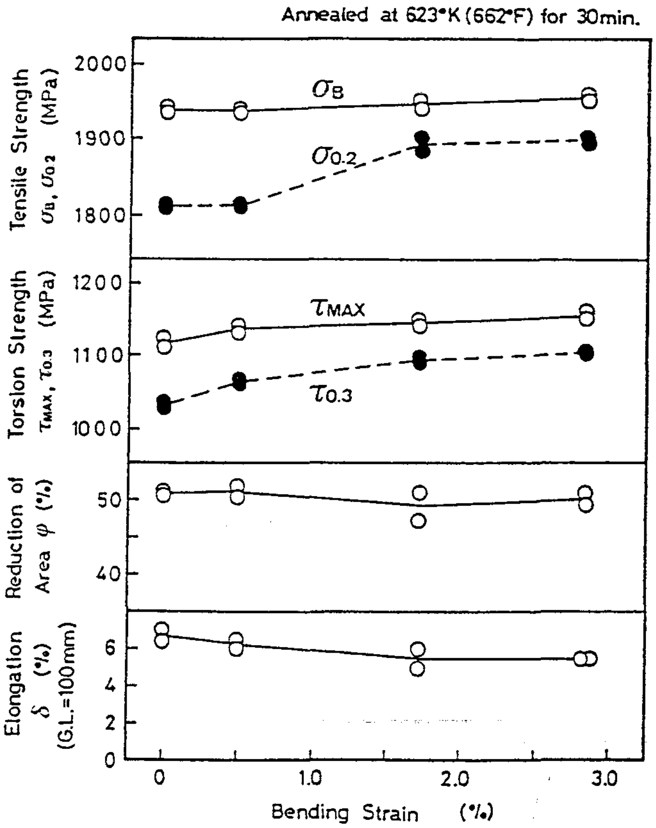



Fig. 2 - The effect of imposed-strain on mechanical properties

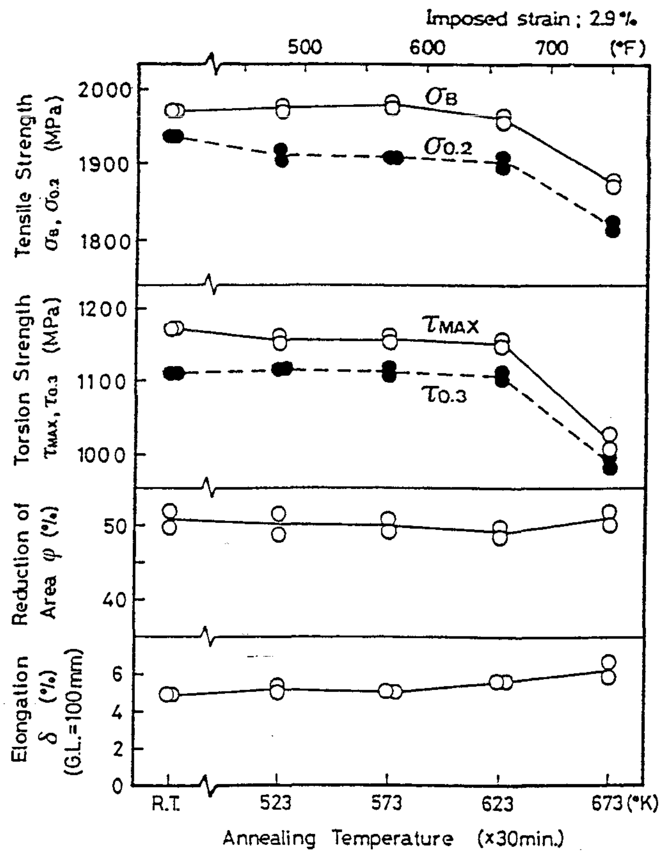



Fig. 3 - The effect of low-temperature annealing on the mechanical properties of strain-imposed steel wire

example, the data for steel wire with tensile strength of 1960MPa treated by cyclic bending with 2.9% strain.

According to this figure, all properties of the steel wire when kept below 623°K (662°F) show little change from those before low-temperature annealing. Only for the steel wire kept at 673°K (752°F) was the tendency observed that $\sigma_B$, $\sigma_{0.2}$, $\tau_{MAX}$ and $\tau_{0.3}$ decrease respectively and that the value of the elongation increases slightly.

ESTIMATION OF THE SAG RESISTANCE BY HYSTERESIS LOOP AREA METHOD - According to S.T. Furr, there is a correlation between the hysteresis loop area in the Bauschinger Torsion Test, as shown in Figure 4, and the sag of coil spring; the larger the area, the better the sag resistance(4). Thus, prior to the test we studied the relation between the hysteresis loop area of the steel wire and the residual shear strain in the coil spring clamping test.

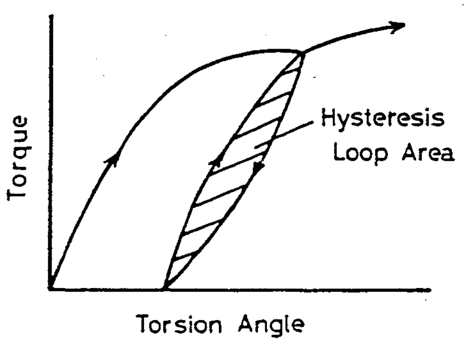



Fig. 4 - Bauschinger Torsion Test

The conditions of the Bauschinger Torsion Test were: wire diameter of 9.5mm; chuck interval of 475mm; and torsion angle of 360°. The hysteresis loop area was calculated by Image-Analyser based on the torque-torsion angle curve. In the spring clamping test, the coil spring was kept for 100 hours at room temperature under a clamping stress of 1180MPa.

Figure 5 shows the relation between the hysteresis loop area and the residual shear strain that came out through measurement of various specimens. The relation enabled us to confirm a good correlation between the two factors.

Thus, it became clear that this method enables us to estimate the sag resistance. We therefore used the method to estimate the effect of strain-imposing to improve the sag resistance. Figures 6 and 7 show the results of our estimations.

Figure 6 shows the relation between the hysteresis loop area and the value of imposed strain on steel wire with tensile strength 2070MPa during cyclic bending at warm temperatures. As the strain increases, the hysteresis loop area also increases, which shows that cyclic bending improves sag resistance.

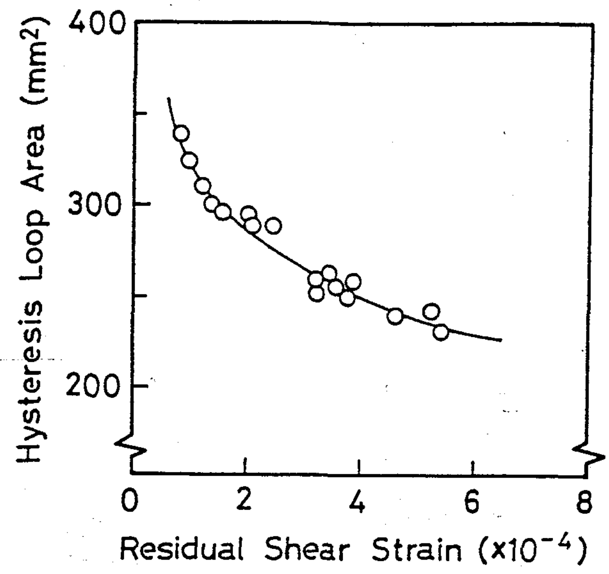



Fig. 5 - Relation between the hysteresis loop area and the residual shear strain as determined by clamping test ( $\tau$=1180MPa for 100hrs.)

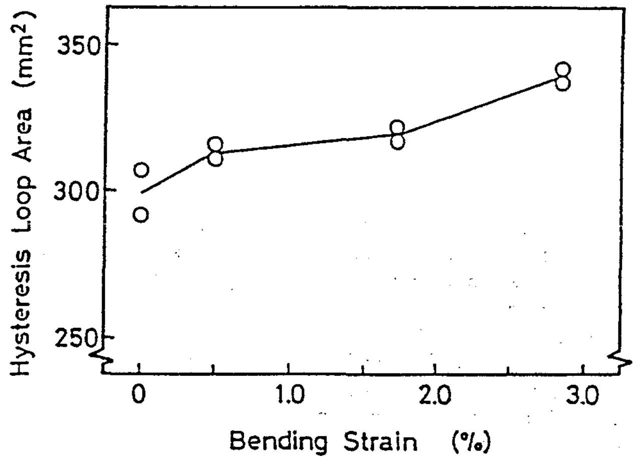



Fig. 6 - Relation between the hysteresis loop area and imposed strain on steel wire with 2070MPa tensile strength

For our test, we produced steel wires of varying degrees of strength, some treated by only quenching and tempering, but others additionally treated by imposing strain through cyclic bending with 2.9% strain. In Figure 7, the hysteresis loop areas of the respective steel wires are plotted against tensile strength. Figure 7 shows that as tensile strength increases, the hysteresis loop area also increases, regardless of whether strain is imposed, and that enhancing tensile strength is effective in improving the sag resistance. Also it is clear that strain-imposing is effective in improving the sag resistance, because the hysteresis loop areas of the strain-imposed steel wires are approximately 13% larger than those of the conventional steel wires of the same tensile strength.

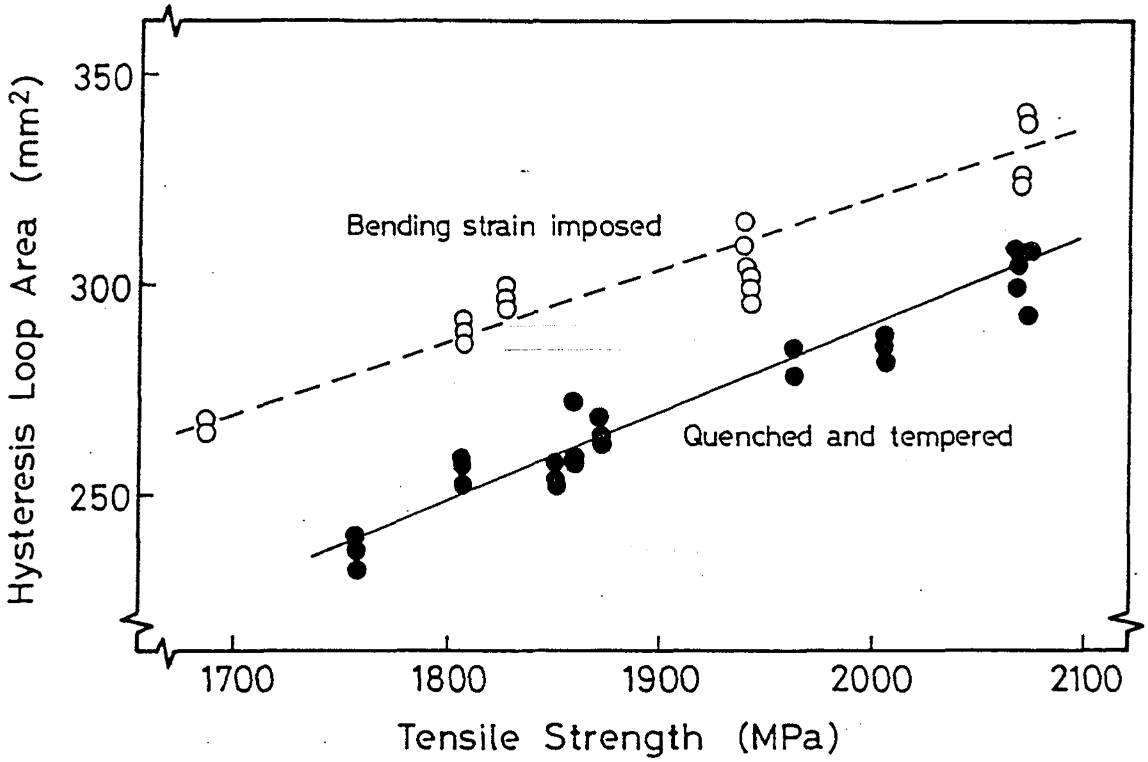



Fig. 7 - The effect of strain-imposing on hysteresis loop area

TESTS OF COIL SPRINGS

As the above tests made it evident that strain-imposed steel wire has high sag resistance, we next tested sag and fatigue properties of cold-formed coil spring. One coil spring group was composed of steel wire treated by cyclic bending with 2.9% strain after quenching and tempering, and the other coil spring group was composed of steel wire treated by only quenching and tempering. The dimensions and manufacturing conditions of the tested coil springs are shown in Tables 2 and 3.

SAG RESISTANCE - Sag resistance was calculated from measurements of load loss under the stress of 1180MPa for 100 hours by clamping tests at room temperature. The results of these tests are shown in Figure 8.

Figure 8, like Figure 7, shows a comparison of the above two groups of coil springs with regard to the residual shear strain against the tensile strength after a clamping test. As with the estimation of sag resistance by the Hysteresis Loop Area Method, Figure 8 shows that as the tensile strength increases, the residual shear strain decreases, i.e., sag resistance increases. And, comparing the two groups of coil springs at the same tensile strength, the residual shear strains of the strain-imposed coil springs are approximately one half of those of the other coil springs. In other words, the strain-imposed coil springs have high sag resistance.

Table 2 - Dimensions of the test coil springs

| | |
|---|---|
| Wire Diameter | 9.5 mm |
| Mean Coil Diameter | 60 mm |
| Free Height | 105 mm |
| Total Number of Coils | 5.5 |
| Number of Effective Coils | 3.5 |
| Spring Rate | 112.8 N/mm² |

Table 3 - Manufacturing conditions of the test coil springs

| | | |
|---|---|---|
| Low-temperature annealing (after formed) | | 623°K × 30 min. (662°F) |
| Shot peening | shot balls | 0.8 mm$^{\varphi}$ cutted wire |
| | arch height | 0.43 mm |
| | coverage | more than 95% |
| Low-temperature annealing (after shot peening) | | 503°K × 20 min. (446°F) |
| Pre-setting | | $0.62 \times \sigma_B$ (twice) |

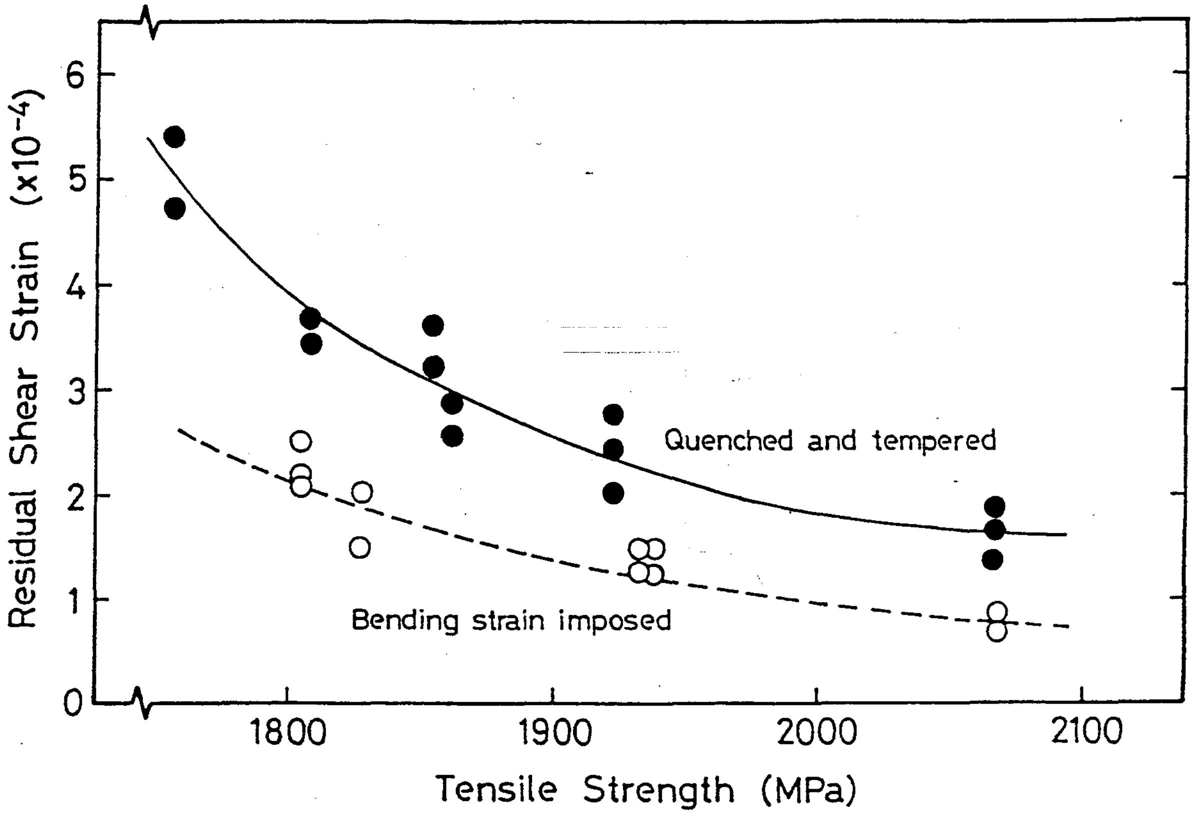



Fig. 8 - The effect of strain-imposing on sag of coil springs

For example, the residual shear strain of the strain-imposed coil spring with tensile strength of 2060MPa is 1 $\times 10^{-4}$ or less while the other is 2 $\times 10^{-4}$ or less. This shows it is possible to produce steel wire with excellent sag resistance by imposing strain. Also it is clear that, when imposing strain on steel wire with tensile strength of 1815MPa, the sag resistance attained is the same as that for steel wire with tensile strength of more than 2060MPa treated by only quenching and tempering. This shows it is possible to avoid damaging cutting tools and decreasing the shot peening effect, which, along with other difficulties, occur in the process of coil spring manufacturing as the tensile strength of the steel wire increases.

FATIGUE LIFE - A strain control type cycle testing machine of 5Hz was used to test the fatigue life. The test conditions were: mean stress of 638MPa; stress amplitude of 540MPa; and cycle limit of 300,000 cycles.

The results of the fatigue tests on the coil springs that were made of strain-imposed steel wire and conventional steel wire are shown in Table 4. Fatigue failures were not observed in any of the tested coil springs after 300,000 cyclic fatigue tests, which indicates the strain-imposed coil springs have sufficient fatigue life for commercial use.

Table 4 - Fatigue test results of the test coil springs

| Kinds of steel wire | Tensile strength of steel wire $\sigma_B$ MPa | Fatigue life $\times 10^3$ cycles $\tau = 638 \pm 540$ MPa |
|---|---|---|
| Quenched and tempered | 1805 | > 300 (n=5) |
| | 2001 | > 300 (n=7) |
| Strain-imposed | 1805 | > 300 (n=5) |
| | 2070 | > 300 (n=5) |

Figure 9 shows the results of sag measurements on coil springs of varying degrees of strength after the above 300,000-cycle fatigue test. The residual shear strains of all strain-imposed coil springs were 1 $\times 10^{-4}$ or less, which confirms that they have high sag resistance.

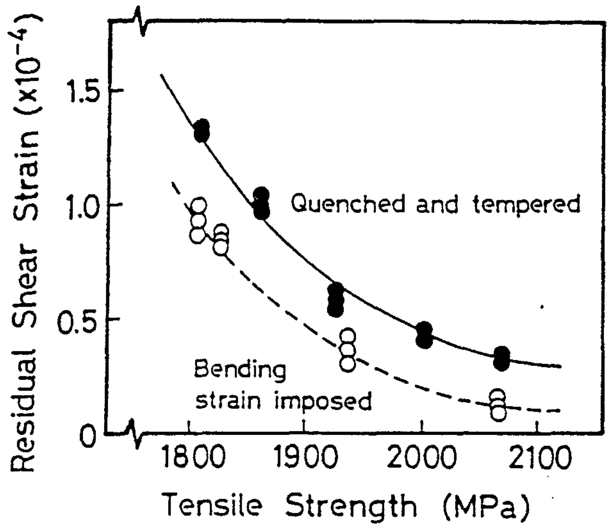



Fig. 9 - Residual shear strain after 300,000-cycle fatigue test of coil springs

DISCUSSION

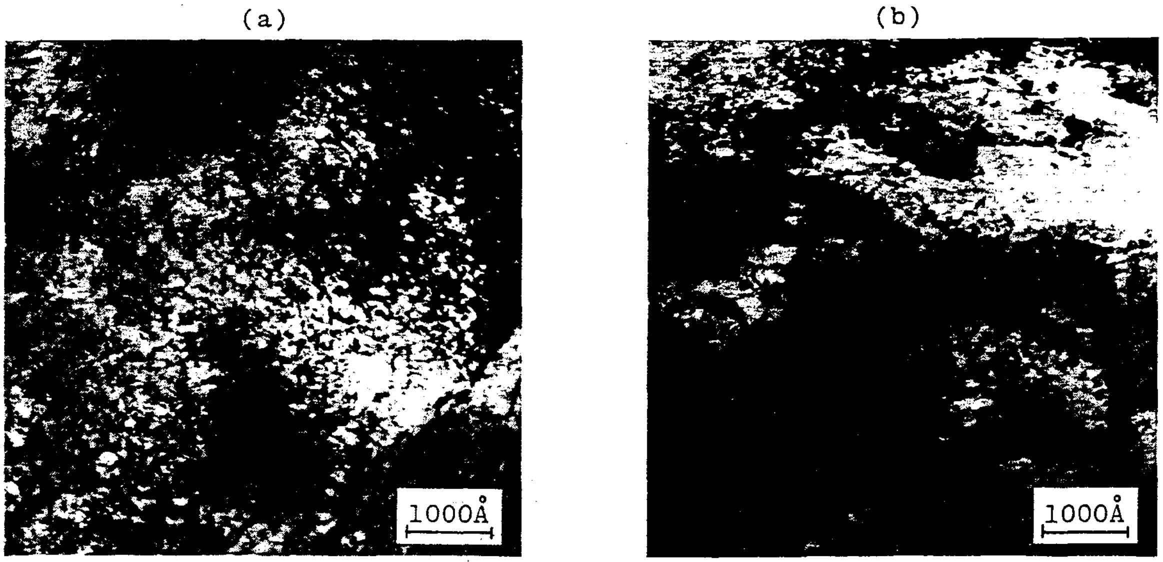
The mechanism by which sag resistance is improved in strain-imposing is presumed to be as follows: strain-imposing at warm temperatures results in the increase, and simultaneous interlocking, of dislocations. As the dislocation density increases, a dislocation network, i.e., a rigid structure, is formed. Therefore, the free dislocations that cause sagging decrease in number and sag resistance is improved.

Photograph 1 shows transmission electron micrographs of steel wire treated by only quenching and tempering and steel wire additionally treated by cyclic bending with 2.9% strain. In Photo.1 (a) of the former, there can be observed numerous dislocations in a comparatively free condition that cause sagging.

On the other hand, as shown in Photo.1 (b) of the latter, the dislocations have multiplied and have become piled up and interlocked with one another, and few dislocations are in a very free condition. This fact allows us to presume that sag resistance has been enhanced.

CONCLUSION

It has become evident that steel wire produced of Si-Cr steel (SAE 9254) through quenching, tempering, and then strain-imposing, has high sag resistance when used for cold-formed coil spring.
(1) In the case of coil spring made of this wire with tensile strength of 2060MPa, the residual shear strain after a clamping test with clamping stress of 1180MPa for 100 hours is $1 \times 10^{-4}$ or less.
(2) The same sag resistance can be attained for strain-imposed steel wire of 1815MPa tensile strength that can be attained with conventional steel wire of more than 2060MPa tensile strength. This shows it is possible to avoid damaging cutting tools and decreasing the shot peening effect, which, along with other problems, occur in the process of coil spring manufacturing as the tensile strength of the steel wire increases.
(3) The strain-imposed coil spring has durability of more than 300,000 bending cycles under the stress of 638±540MPa and has sufficient fatigue life for commercial use.




Photograph 1 - Transmission electron micrographs of steel wires
(a) quenched and tempered (b) 2.9% bending strain imposed

(4) The mechanism by which sag resistance is improved in strain-imposing is as follows: strain-imposing at warm temperatures results in the increase, and simultaneous interlocking, of dislocations. As the dislocation density increases, a dislocation netword, i.e., a rigid structure, is formed.

Possible methods for imposing strain on steel wire include torsion, drawing, and several others, in addition to the cyclic bending method. However, of these methods, the cyclic bending method appears to be the easiest and most practical to apply to a mass-production equipment line.

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