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Development of High-Strength Suspension Coil Springs in which Corrosion Fatigue Strength is Important

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ABSTRACT

For the weight reduction of suspension coil springs for automobiles, high-strength steel has been developed. But, in general, strength and corrosion fatigue are contradictory. Then the technological basis is to raise durability and sag resistance, and further improvement of the corrosion fatigue strength is important.

As a solution for the problem, element design which improved the performance against corrosion and optimum condition of shot peening process were studied. Thus high-strength suspension coil springs have superior corrosion fatigue strength, compared with the spring made of SAE9260 were developed.

Moreover, as a new basic evaluation, corrosion fatigue test of springs with an artificial pit was worked out.

INTRODUCTION

Recently the demand of the fuel economy improvement for the automobiles has been strengthened from a point of resources and environment. Therefore, automotive parts have been reduced as one step. As a matter of course in case of suspension coil springs they are lightened to satisfy the demand. This is the same meaning as raising the design stress of the springs, and it is necessary to use the high-strength material. In making to a high-stress spring, the hardness of springs has been made higher to keep up basic spring performance, which are sag resistance and durability. But it was reported that it causes the adverse effect at the point of corrosion fatigue. [1,2]

In suspension parts for the automobiles, it is important to take notice of corrosion fatigue strength because they are used in the environment which their coating is damaged by the stone chips and by salt pollution. [3] But it is difficult to indicate it in a quantitative way because the factors which effect corrosion fatigue strength of springs, which are hardness, material compositions, residual stress and so on, are complexly related one another. For that reason the examination methods to evaluate corrosion fatigue strength have not been established yet. [4]

Then, in this development, examining a new method to evaluate corrosion fatigue strength, both materials and the manufacturing methods of springs were improved, and developed since it is essential not only the improvement of the corrosion fatigue strength but the raising durability and sag resistance as the technological basis.

ELEMENT DESIGN

Figure 1 shows an idea of the improvement of corrosion fatigue strength on materials, and the steps were examined.

THE QUANTITY OF CORROSION

To confirm the effect of the adding Ni on corrosion the salt spray test (SST) was examined, and the depth of corrosion pit and the quantity reducing by corrosion were examined. Figure 2 shows the specimen shape. Moreover, the corrosion cycle was done as follows.

{Salt spray (5%NaCl)35℃,3hrs. + Dryness 35℃,21hrs.}
×20cycles

The quantity reducing by corrosion was measured weight before and after corrosion, removing the corrosion products by 10% citric acid ammonium. The depth of corrosion pit measured the maximum pit which had been observed in the section where the specimens had been cut. The measurement result of the quantity reducing by corrosion is shown in Figure 3 and of the maximum depth of corrosion pit in Figure 4. As Ni increases in the chemical composition, the quantity reduced by corrosion decreases, which converges around 0.6kg/m² when adding Ni by 0.4%. Moreover, when adding by 0.55%, the maximum depth of corrosion pit becomes about one-third compared with additive-free one. Thus, it is confirmed that

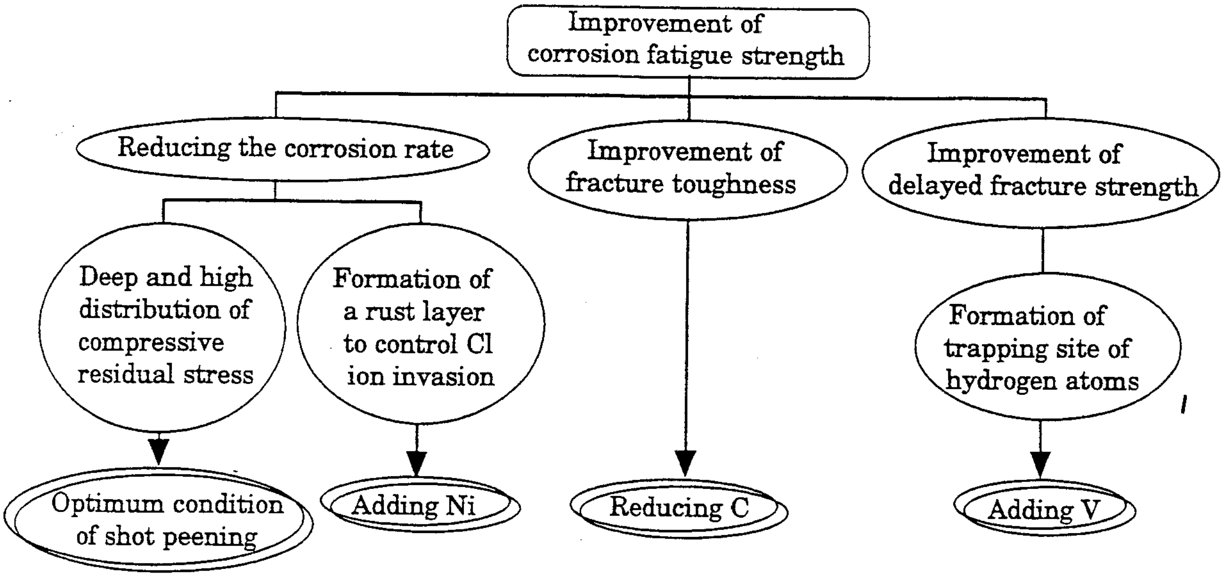

Fig.1 Conception of improvement of corrosion fatigue strength

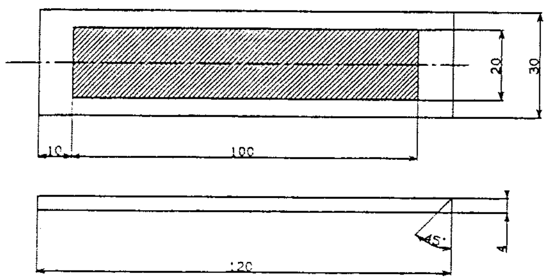

Fig.2 Specimen dimension for SST
Corrosion part is shadow.

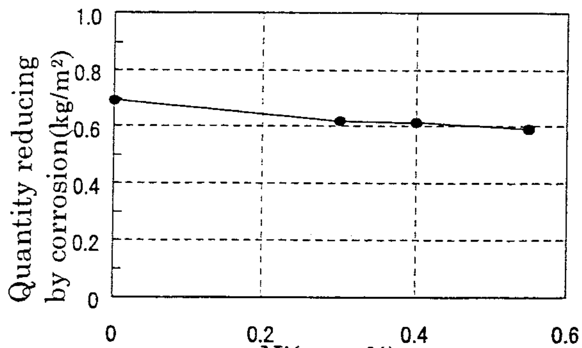

Fig.3 Effect of adding Ni
0.55%C,2%Si,0.7%Mn and 0.2%V steel,
53.0HRC

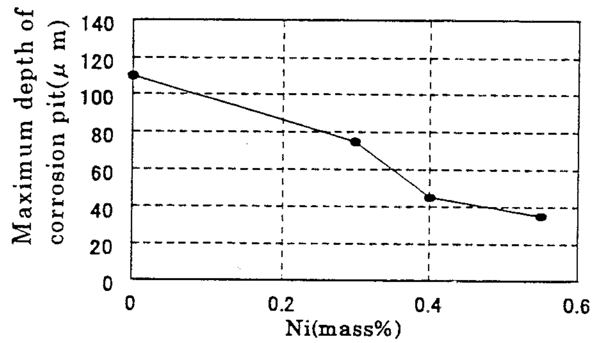

Fig.4 Effect of adding Ni
0.55%C,2%Si,0.7%Mn and 0.2%V steel,
53.0HRC

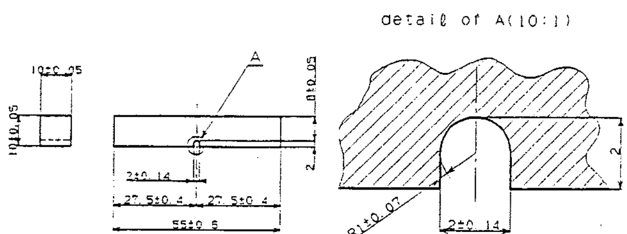

Fig.5 Specimen dimension for Charpy impact test

adding Ni has an effect on reducing corrosion, especially the maximum depth of corrosion pit.

FRACTURE TOUGHNESS

To confirm of the effect of reducing C and adding V on fracture toughness the Charpy impact test was examined. Figure 5 shows the specimen shape. The result of the effect of reducing C is shown in Figure 6 and the result of the effect of adding V is shown in Figure 7. The less C becomes, the larger the impact value becomes. Besides, the more V is added, the larger the impact value becomes as well. Thus, it turns out that less C as well as adding V has an effect on the toughness.

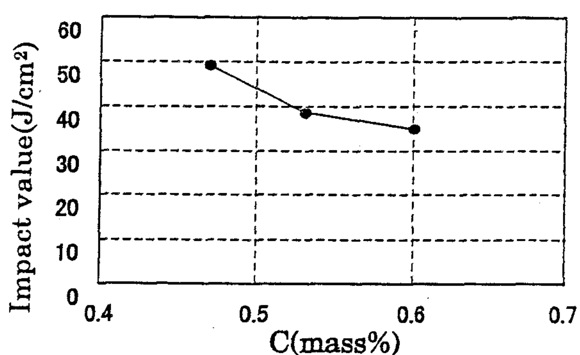

Fig.6 Effect of reducing C
2%Si,0.7%Mn,0.55%Ni and 0.2%V steel, 53.0HRC

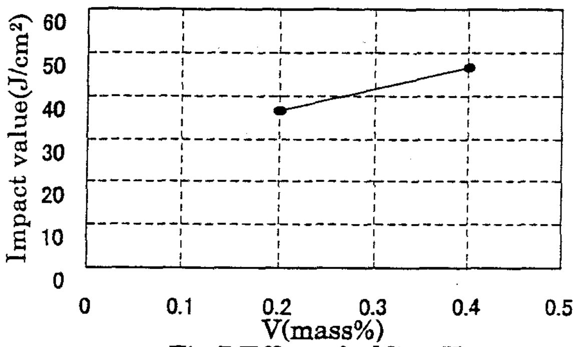

Fig.7 Effect of adding V
0.45%C,2.5%Si,1.3%Mn,0.2%Mo and1.0%Ni steel,55.0HRC

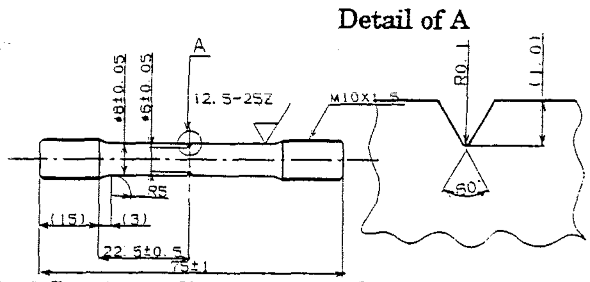

Fig.8 Specimen dimension for delayed fracture test

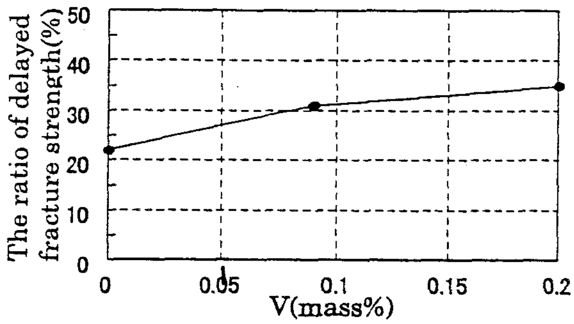

Fig.9 Effect of adding V.
0.53%C,2%Si,0.7%Mn and 0.2%Ni steel, 53.5HRC

DELAYED FRACTURE STRENGTH

To confirm the effect of adding V on delayed fracture strength the delayed fracture test was examined. Figure 8 shows the specimen shape. After the specimens were dipped in 5% hydrochloric acid for 30 minutes, they were washed in water and were dried. The examination began 5 minutes later from the hydrogen charge end. The specimens were held under constant tension and were measured until breaking. The ratio of delayed fracture strength is defined as follows.

(The ratio of delayed fracture strength) = (Unbroken strength for 100 hours after the hydrogen charging) ／(Strength without the hydrogen charging)

Figure 9 shows the examination result. It shows the ratio of delayed fracture strength increases as V is added. Thus, it turns out that adding V has an effect on the resistance against the delayed fracture.

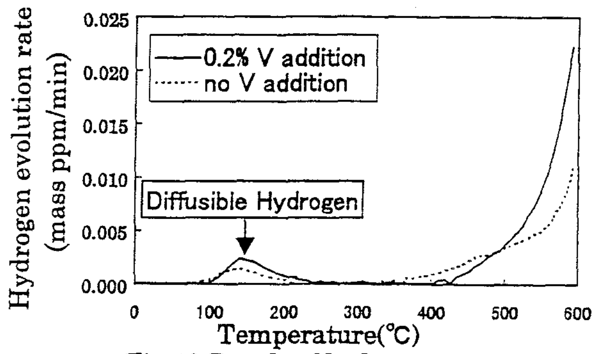

Fig.10 Result of hydrogen analysis
0.55%C,2%Si,0.7%Mn and 0.2%V steel

HYDROGEN ANALYSIS

To confirm the effect of the hydrogen trap of adding V the hydrogen analysis was examined.

The specimens were column shape, diameter was 14mm and length was 20mm. The way to charge the hydrogen was the same as in the delayed fracture test above-mentioned. The examination began 5 minutes later from the hydrogen charge end. Figure 10 shows the examination result. Because the peak of diffusion hydrogen shifts to the high temperature side, it is recognized the effect of the hydrogen trap by adding V. [5,6]

MATERIAL

As a result of an component design, the quantity of additive metal is restrained as less as possible because of the spring performance except for corrosion fatigue and the material cost, which leads to making the developed steel 0.47%C, 0.55%Ni, and 0.2%V in the end. Material was made with these elements and evaluated. The chemical compositions of both the developed steel and SAE9260 are given in Table 1 and the dimensions of the springs used in the experiment are given in Table 2 and the manufacturing process is shown in Figure 11.

Table1 Chemical composition (mass %)

	C	Si	Mn	P	S	Ni	V	Cr
SAE9260	0.60	2.00	0.85	0.020	0.022	-	-	-
Developed steel	0.47	2.00	0.70	0.014	0.005	0.55	0.20	0.20

Table2 Dimensions of the springs used for test

Wire diameter (mm)	Coil diameter (mm)	Free height (mm)	Number of active coils	Spring rate (N/mm)
φ 11	φ 100	311	5.29	27.2

Shaving → Heating → Coiling → Oil quenching → Tempering →Setting ① → Shot peening → Tempering → Secondly setting ②

① For fatigue test of springs with artificial pit

② For corrosion fatigue test of springs without coating

Fig.11 Spring manufacturing process

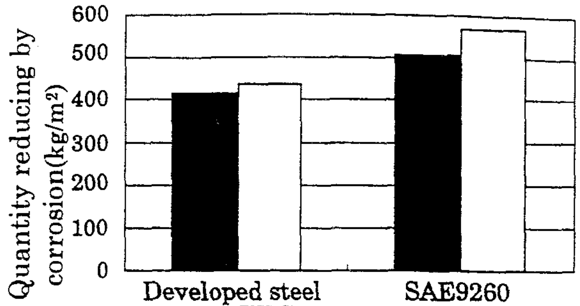

Fig.13 Comparison of the quantity reducing by corrosion

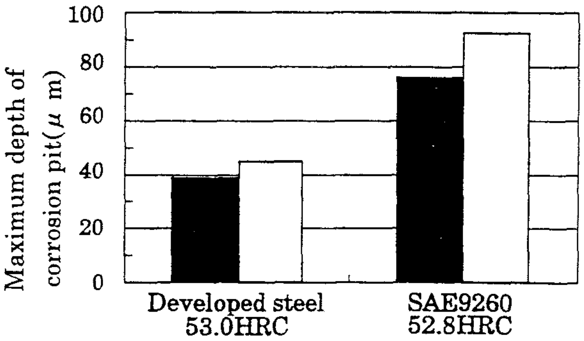

Fig.14 Comparison of the maximum depth of corrosion pit

MATERIAL EVALUATION

SALT SPRAY TEST (SST)

To compare the difference of corrosion in the materials, the SST was conducted. The examination method is similar to the above-mentioned. The shape of corrosion pit is shown in Figure 12, the quantity reducing by corrosion is shown in Figure 13, and the maximum depth of corrosion pit is shown in Figure 14. It can be said that developed steel makes the corrosion less, the corrosion pit shallower, the surface smoother and stress concentration decrease than SAE9260. It also appears that the quantity reduced by corrosion improves by about 20% and the maximum depth of corrosion pit by about 50%.

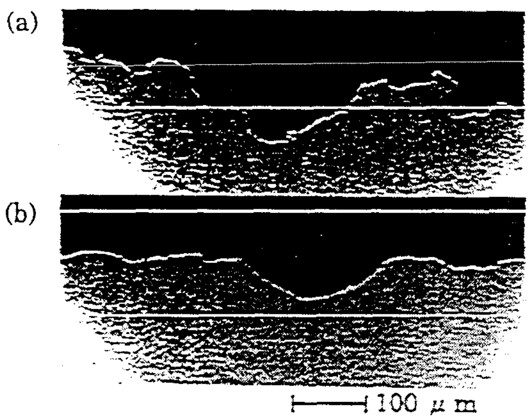

Fig.12 The shape of corrosion pits (a)SAE9260 (b)Developed steel

ROTATING BENDING CORROSION FATIGUE TEST

To compare corrosion fatigue strength from the difference of the level of corrosion with the material elements, the rotating bending corrosion fatigue test was done. The method of making the specimens was that after they were processed coarsely and were heat-treated, and then were processed to finish up afterwards. (Figure 15)

The specimens were made to corrode by SST, after that the rotating bending fatigue test was done. The result is shown in Figure 16, and the difference in metals is clearly seen. Though the developed steel is harder than SAE9260, the fatigue limit increases by about 22% if both steels are compared by it. Then the difference of both steels were investigated. It is thought that the developed steel becomes advantageous against corrosion when compared to the shapes of corrosion pits of both steels, the depth of corrosion pit of it is shallower than SAE9260, and smoother shape, (the aspect ratio of it is smaller) as shown in Figure 12,and that, as a result, the fatigue durability increases. [7,8] Moreover, the corrosion section is shown and the result of EPMA is shown in Figure 17. In the developed steel, the concentrate of Ni is seen in the rust layer and the amount of Cl is a little at the position where Ni exists. Thus, it is thought that there is an effect to disturb the attack of Cl to the metal part by the existence of Ni. [9]

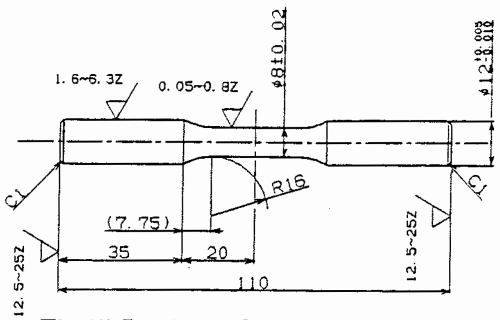

Fig.15 Specimen dimension for rotating bending corrosion fatigue test

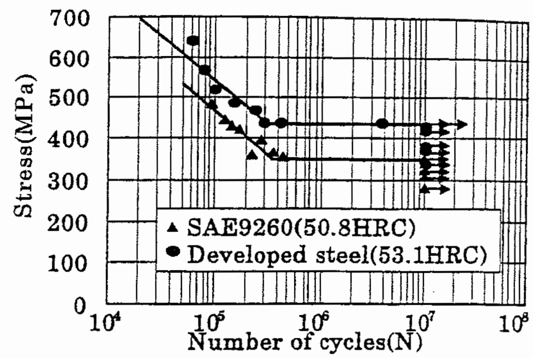

Fig.16 Result of rotating bending corrosion fatigue test

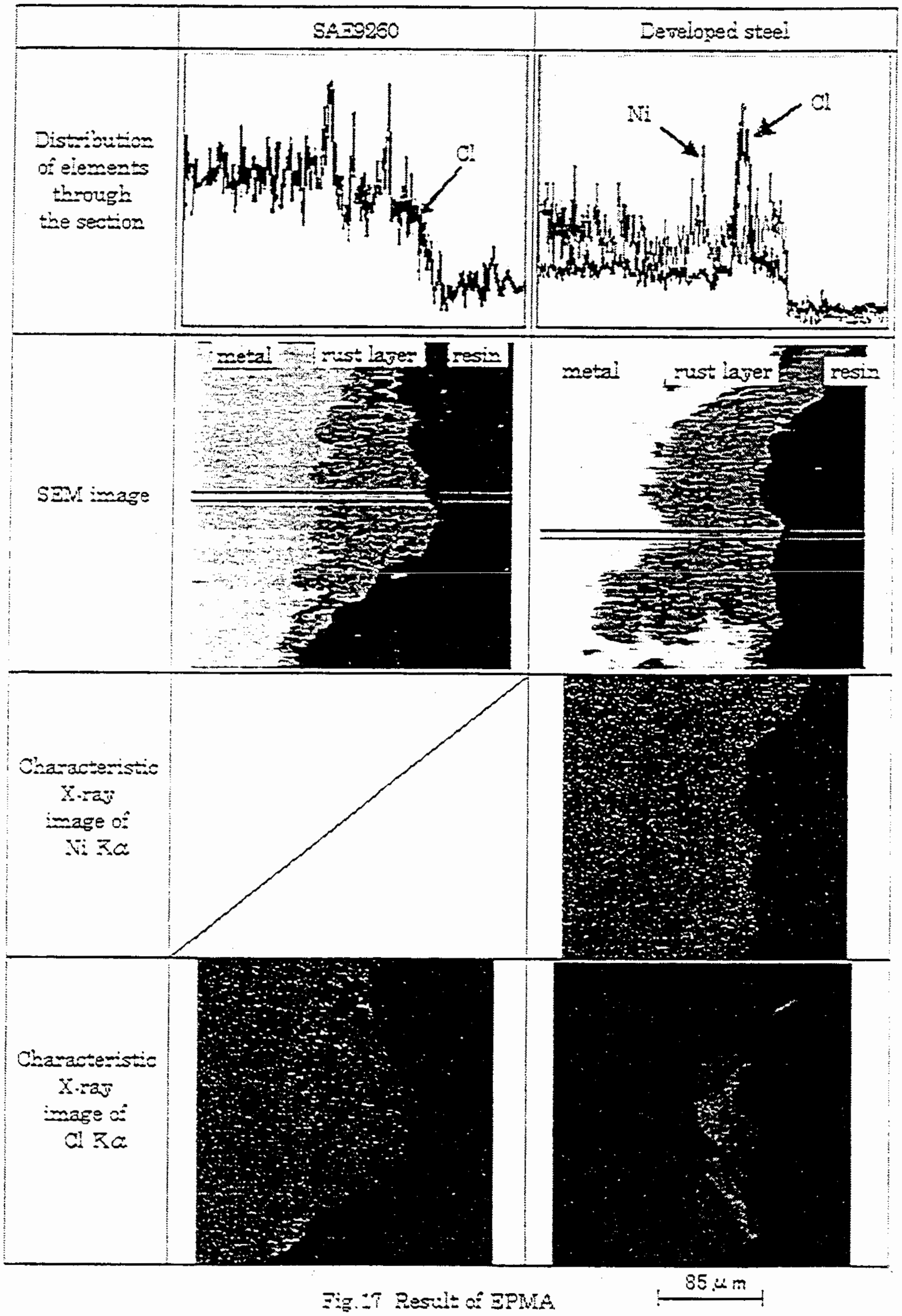

Fig.17 Result of EPMA

SPRING EVALUATION

To compare corrosion fatigue strength of the developed steel and SAE9260, the springs of both steels were tested.

CORROSION FATIGUE TEST OF SPRINGS WITHOUT COATING

At first the corrosion fatigue test was done by using the springs which were of same hardness, the same material components and which were given shot peening without coating to investigate the influence of the compressive residual stress on corrosion fatigue strength. As for the procedure, the springs received shot peening were when made to corrode; and the durability was examined afterwards. The corrosion cycles were similar to the case of SST as stated above.

The fatigue test was done by using springs of the developed steel, to which the residual stress distributed before corrosion as shown in Figure 18, and after corrosion by SST. In this case the relation between the residual stress of corrosion surface and the corrosion fatigue durability is shown in Figure 19.

From Figure 19 it can be said that there is a correlation in the residual stress and the corrosion fatigue durability and that it is effective to the corrosion fatigue that as high compressive residual stress as possible is given to the surface after corrosion. For that it is necessary to reduce corrosion or to distribute the compressive residual stress deeply.

Secondly, Figure 20 shows the corrosion fatigue test result of the springs of the developed steel to which the compressive residual stress is as deep and distributed as mentioned above and of the springs of SAE9260. The springs of developed steel have the corrosion fatigue life more than the equal though hardness and the examination stress of the springs are raised.

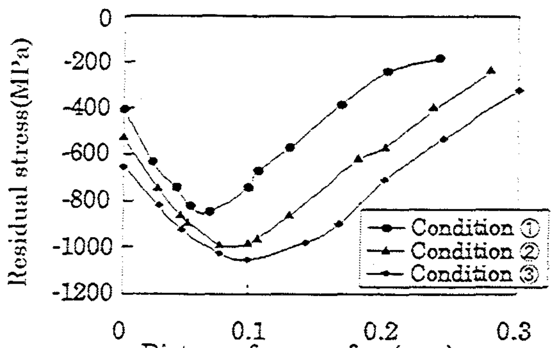

Fig.18 Distribution of residual stress

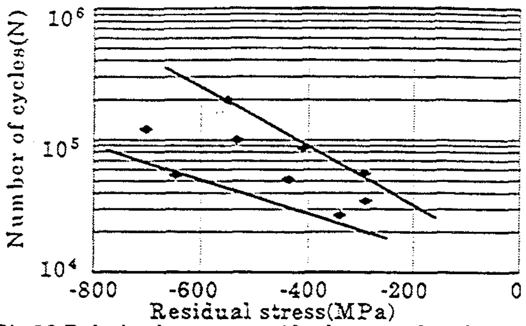

Fig.19 Relation between residual stress of surface and corrosion fatigue life (Developed steel)

$\tau = 490 \pm 294$MPa,52.7HRC

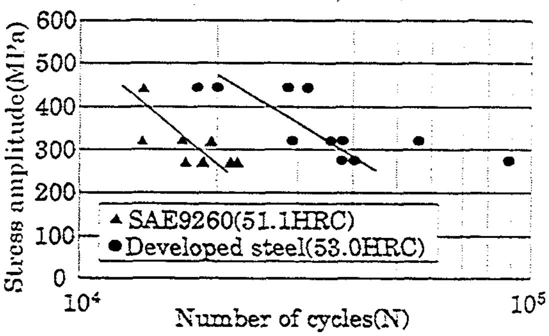

Fig.20 Result of corrosion fatigue life of springs without coating mean stress:735MPa

FATIGUE TEST OF SPRINGS WITH AN ARTIFICIAL PIT

It is thought that one of the causes of the strength decrease due to corrosion is the stress concentration near the pit. However various influences are included in the corrosion test when the influence of hardness on the crack receptivity of the material is examined. Then, as a new evaluation method, the fatigue test of the springs which were given an artificial pit without shot peening to investigate the influence of the stress concentration near the pit purely was done.

As for the method of making an artificial pit, masking with a small hole was done on the surface of the spring, and the electrolytic grinding was done up to the depth of the aim. The ammonium chloride was used for the electrolysis liquid. The fatigue test was done afterwards, the shape of an artificial pit like Figure 21 was observed with SEM, and shape was measured.

Figure 22 shows the relation between the depths of an artificial pit on 3 levels and the fatigue durability in case of the springs of developed steel. The result of fatigue test of the springs with an artificial pit is that the fatigue durability falls as metal hardness becomes increased even with the same depth of pits. That is shown a similar tendency to the result of corrosion fatigue test on past studies about the relation between hardness and corrosion fatigue. (1) But when the depth of pit is shallow, the fatigue durability increases when the metal is harder.

This is corresponding to that the smoother the surface roughness of sample approaches, the smaller the stress concentration becomes, and that results in the improvement of fatigue strength. [6,7]

Moreover, the result of fatigue test with an artificial pit of the springs of the developed steel and SAE9260 is shown in Figure 23. It can be said that crack receptivity of this result is low even if hardness improves as well as corrosion fatigue test result of the springs without coating.

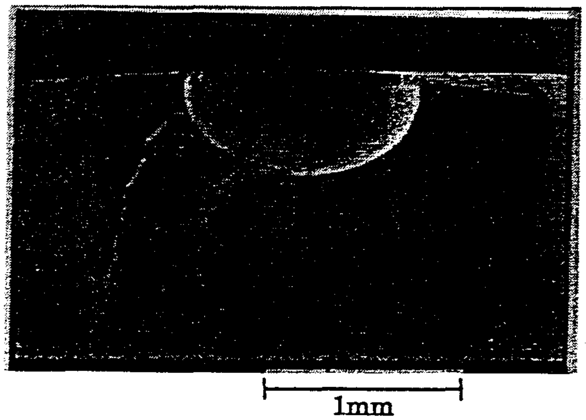

Fig.21 An example of an artificial pit

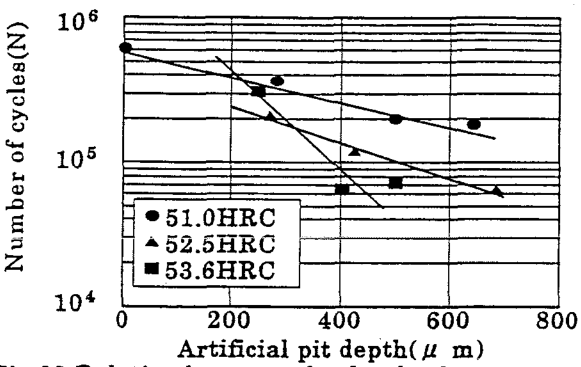

Fig.22 Relation between the depth of an pit and fatigue life(Developed steel)
$\tau = 490 \pm 294$MPa

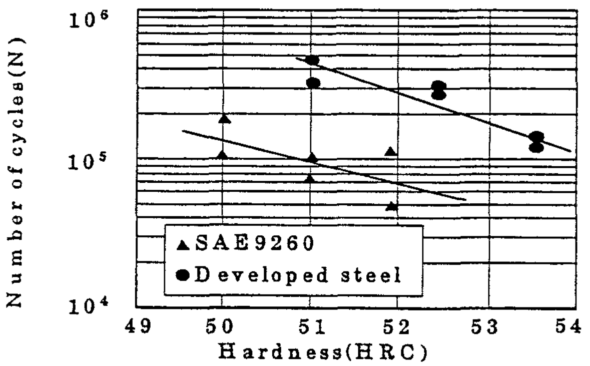

Fig.23 Relation between hardness and fatigue life
$\tau = 490 \pm 294$MPa, depth of pit=300 μ m

CONCLUSIONS

The following conclusions were obtained result in development of high-strength suspension coil spring by which the improvement of corrosion fatigue strength was gained.

(1)Adding Ni by about 0.55% makes the corrosion of developed steel less, the corrosion pit shallower, the surface smoother and stress concentration decrease.

(2)A combination between reducing C by 0.47% and adding V by 0.2% increases toughness of the developed steel.

(3)It turns out that there is a correlation between the compressive residual stress in the surface after corrosion and the life of corrosion fatigue. Therefore, it is a good idea to make the compressive residual stress distribute deeply before corrosion in order to improve the strength of corrosion fatigue.

(4)As a result of fatigue test of springs with an artificial pit, which is a new evaluation method, it shows the life of fatigue is shortened because of the rise of hardness. This makes it possible to indicate the influence of the only hardness over the strength of corrosion fatigue in a quantitative way.

(5)As a result of both of corrosion fatigue test of springs without coating and fatigue test of springs with an artificial pit, it turns out that the springs of the development steel have high corrosion fatigue even if hardness and the examination stress are improved compared with the springs which have used steel (SAE9260) so far.

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