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Akira Tange, Hiroshi Koyama and Hiroto Tsuji
NHK Spring Co.,Ltd

Jeffrey Schaad
NHK International Corp.

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NHK Spring Co.,Ltd

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ABSTRACT

Warm Shot Peening is a shot peening process within warm temperature range. However, the effect of warm shot peening to fatigue strength was not certain and no substantial study has been made.

The requirements of coil spring with higher fatigue strength and sag resistance have been increasing to obtain the mass saving of vehicle. While several new spring materials have been developed in recent years, the essence of those developments were to make the strength(hardness) of spring higher, so-called high strengthened spring. As for high strengthened spring, the shot peening process becomes further essential to relieve the increased notch sensitivity due to higher strength. However, for the shot peening process to high strengthened spring, the shot with higher hardness is also required. This can decrease the life of both shot and shot peening equipments.

Warm shot peening under the tempering temperature may become one solution to those problems, because the hardness of spring can be temporarily reduced only during the shot peening process. In this paper, the following experimental results concerned with the effect of warm shot peening, are summarized.

1. The relation between spring fatigue life and hardness under one warm shot peening temperature.
2. The relation between spring fatigue life and shot peening temperature.
3. Effects of residual stress, coverage, and surface hardness to fatigue life.

INTRODUCTION

For the purpose of saving energy and natural resourses, the demand of weight-saving of automotive parts has been increasing. As for coil spring, its design stress increase by 100MPa can be said to create the 10% weight-saving of coil spring. Therefore, while the design stress was 800 to 900MPa before the oil crisis(1974), the design stress of most coil springs has been 1000 to 1100MPa in recent years.

The continuous requirements for weight-saving increase the design stress up to 1200MPa for newly designed automotive coil spring. In order to increase the design stress of coil spring, several new spring materials have been developed in recent years[1),2),3)]. The hardness of spring with these newly developed spring material should be increased to meet with the higher design stress. Although these new materials are considered to keep the toughness with the hardness increase, there seems to be some increase of the notch sensitivity with the hardness increase. Therefore, the shot peening process becomes more important for the high strengthened coil spring. For the shot peening process to high strengthened spring, the shot with higher hardness is also required. This can decrease the life of both shot and shot peening equipments. Warm shot peening process under the tempering temperaturebecomes one solution to those problems. NHK Spring Co.,Ltd has applied the warm shot peening process to its automotive suspension coil spring manufacturing line since 1989.

The aim of this paper is to show some experimental results concerned with the effect of warm shot peening and to discuss the mechanism of warm shot peening. Finally, an example of recent automotive suspension coil spring application by 1200MPa design stress can be shown.

EXPERIMENTAL PROCEDURES

Table 1 shows the material and specifications of coil spring applied to the experiments. For the experiments of the relation between the spring hardness and fatigue life, the quenching temperature is 1193K constant and the tempering temperature is ranged from 573 to 723K to have the spring hardness of 510, 550, 600, and 650HV. For the experiments of the relation between the shot peening temperature and fatigue life, the tempering temperature is 623K constant to have the spring hardness as 600HV. Warm Shot Peening Processes were carried out by heat circulated oven. The heating time is 20 mins under the temperature ranged fro 473 to 673K. Table 2 shows the shot peening conditions.

Table 1. Material Chemical and Spring Specifications

	C	Mn	Si	Cr
JIS G 4801 SUP7M	0.59	0.85	2.05	0.15 wt%

Wire Dia.	Mean Coil Dia.	Effective. No. of Coil	Spring Rate
9.0 mm	84.9 mm	5.5	19.1 N/mm

SUP7 equivalent to SAE9260.

Table 2. Shot Peening Conditions

Shot Dia.	Shot Hardness	Shot Speed	Arc Height
0.87mm Cut-Wire	520~ 570HV	66m/sec	0.32~ 0.42mmA

EXPERIMENTAL RESULTS AND DISCUSSIONS

THE RELATION BETWEEN THE SPRING HARDNESS AND FATIGUE LIFE – Fig.1 shows the relation between the spring hardness and fatigue life at the shot peening temperature of both room temperature and 573K. For the spring shot peened at room temperature, the mean fatigue life increases as the hardness increase.

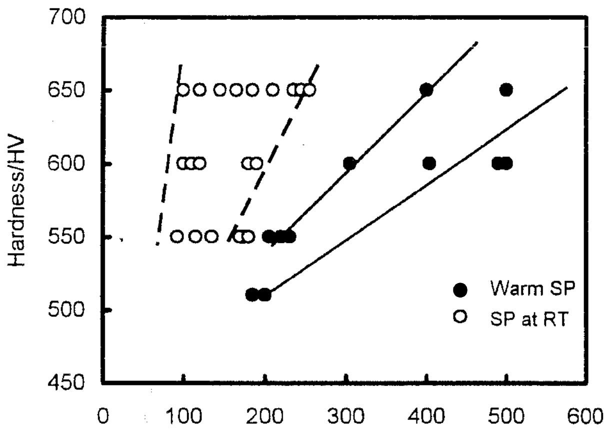

Fig.1 Relation between Spring Hardness and Fatigue Life
637±539MPa, SP Temperature/573K

At the lower limit of fatigue life, the improvements of fatigue life with the hardness increase, however, seem to be small and show many scattering due to the tendency of increasing the notch sensitivity . As for the fatigue life of warm shot peened spring, while the improvements are not so large at 550HV, the improvements increase as the hardness increases. This means that the warm shot peening is more effective to the high strengthened spring. It can be seen from the Fig.1, that the effect is further large at the spring hardness over 600HV.

To explain the above, Photo.1-A and 1-B shows the fractured surface and spring outside surface around the fatigue origin when shot peened at room temperature and 573K.

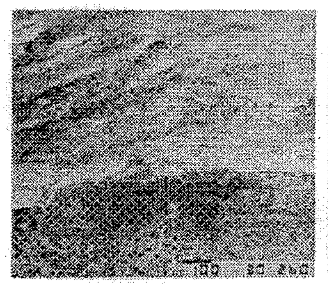

Photo.1-A(SP at R.T.)

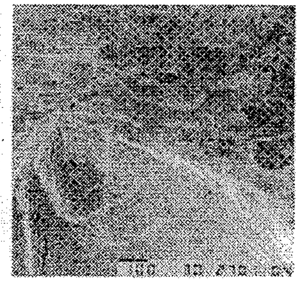

Photo.1-B(Warm SP)

Fatigue Fractured Surface and Outside Surface

Although the fatigue origins at the both cases, occur from the outside surface, the major differences between Photo.1-A and 1-B are the size of shot peened dents and coverage. It can be seen from the Photo.1, that while at the spring surface shot peened at room temperature, the shot peened dents are not clear and the coverage does not seemed to be enough, both dents and coverage at the spring surface warm shot peened at 573K can be seen to be more adequate. Therefore, it can be assumed that the effect of warm shot peening to the fatigue life is the grade of surface deformation, and the surface deformation shot peened at room temperature is not sufficient when the spring hardness is high(over 600HV).

The experimental results shown in the Fig.1 say that the warm shot peening to high strengthened spring over 600HV is a superior process to achieve high fatigue strength and sag-resistance simultaneously.

THE RELATION BETWEEN THE SHOT PEENING TEMPERATURE AND FATIGUE LIFE – Fig.2 shows the relation between the fatigue life and shot peening temperature when the spring hardness is 600HV constant. The Fig.2 also shows the surface roughness of spring after shot peening. The mean fatigue life of warm shot peened spring at the temperature ranged from 473 to 623K, are better than that at the room temperature. The shot peening temperature range to show highest fatigue life seem to be between 523 and 598K. At the temperature of 473K, which is lower than that range, and at the temperature of 623K, which is higher than that range, there seem to be the trends that the fatigue life becomes lower.The maximum surface roughness increases from 10m at the room temperature to 14m at 623K, as the temperature becomes high. This can be caused by the increase of deformation at the surface , as the shot peening temperature increases.

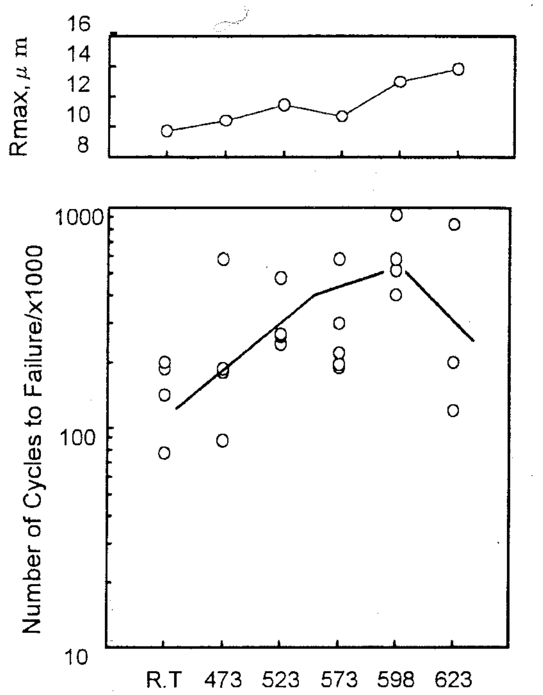

Fig.2 Relation between SP Temperature Surface Roughness and Fatigue Life (600HV)

In the application of warm shot peening process, the spring hardness must not become lower under the shot peening temperature. This means that the temperature of warm shot peening must be lower than the tempering temperature. Therefore, it can be required to know the yield stress at the temperature range of warm shot peening.

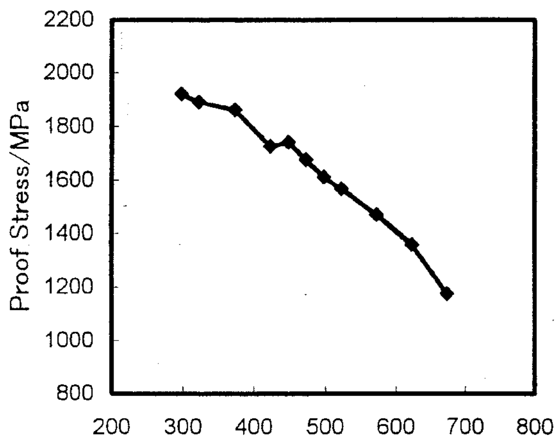

Fig.3 Relation between theTemperature and Proof Stress(SUP7M, 600HV)

Fig.3 shows the 0.2% proof stress(yield stress) of the material(SUP7M) heat-treated to 600HV under the temperature ranged from the room temperature to 673K.

It can be seen from the Fig.3 that the while the proof stress at the room temperature is 1920MPa, the proof stress prominently decreases over 423K , and becomes 1650MPa at 473K and 1350MPa at 623K. The results of the Fig.3 can explain that the shot peening to high strengthened material becomes more effective at the warm temperature ranges due to temporarily decreased proof stress.

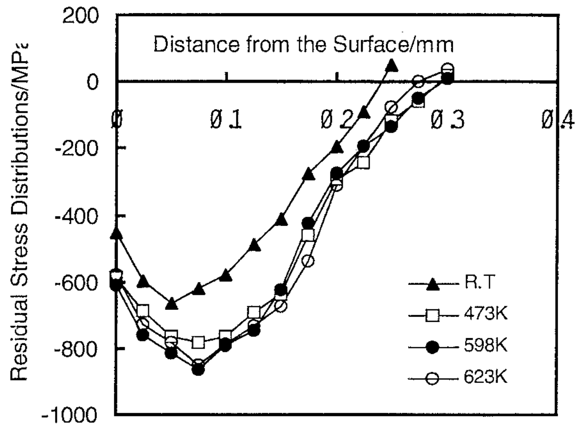

Fig.4 Relation between SP Temperature and Residual Stress

Fig.4 shows the longitudinal residual stress distributions from the surface to inside at the shot peening temperatures of the room temperature, 473, 598, and 623K. It can be seen from the Fig.4 that the compressive residual stresses of warm shot peening are higher than that of shot peening at the room temperature, as for both the surface value and peak value. The depth of the distributions at the warm shot peening is also higher. These experimental results can explain the reason why the warm shot peened spring show higher fatigue life.

As for the reason why the spring shot peened at 473K shows lower fatigue life, it can be assumed from the Fig.4 that due to less deformation the residual stress distributions are relatively lower than the spring shot peened at 598K. In case of the shot peening at 623K, the reasons why the fatigue life becomes lower, can be assumed to be the surface roughness shown in the Fig.2, which can be caused by too much deformation. Additionally, although it is not certain to explain the decrease of fatigue life by the residual stress distributions shown in the Fig.4, the relief of residual stress can be promoted over the temperature of 573K[4]. Therefore, on the shot peened spring at 623K, the relief of residual stress can be assumed to occur during the warm shot peening process simultaneously. Considering the above experimental results and discussions, it can be concluded that the maximum temperature effective to the fatigue life may be around 598K.

SURFACE HARDENING DUE TO STRAIN-AGING – As for the reason why the fatigue life of spring can be improved by warm shot peening, besides the increase of surface coverage and residual stress which were discussed in the section 3.2, the surface work-hardening due to strain-aging can be considered.

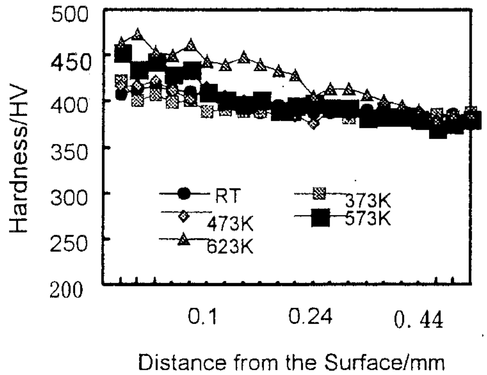

Fig.5-A Hardness Distributions(380HV

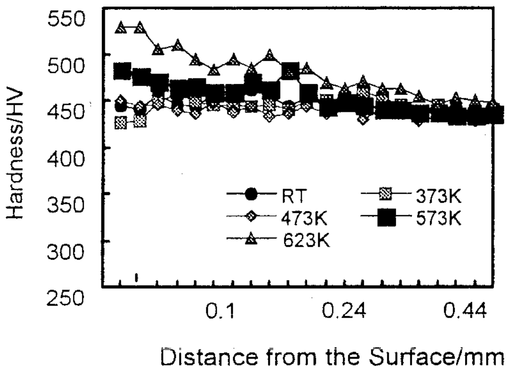

Fig.5-B Hardness Distributions(450HV

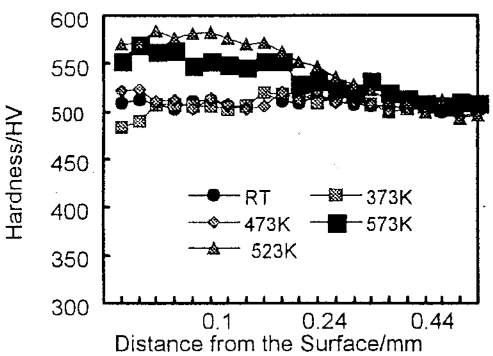

Fig.5-C Hardness Distributions(500HV)

Fig.5-A~D show the detailed hardness distributions around the surface, for spring steel plates with the hardness of 380HV, 450HV, 500HV and 580HV, shot peened at the room temperature, 373, 473, 573, and 623K. It can be noted from the Fig.5-A(380HV) and Fig.5-D(580HV), that while the surface hardness of the spring shot peened at the room temperature, 373, and 473K, increase slightly, those at 573 and 623K do prominently.

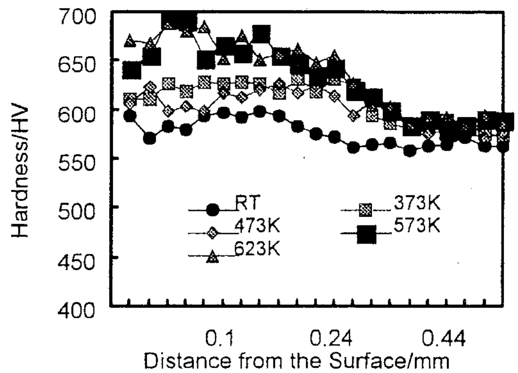

Fig.5-D Hardness Distributions(580HV)

It can be noted from the Fig.5-A(380HV) and Fig.5-D(580HV), that while the surface hardness of the spring shot peened at the room temperature, 373, and 473K, increase slightly, those at 573 and 623K do prominently. The increased value is 50HV for 380HV material. However, for 580HV material. The prominent increase around 150HV can be seen from the Fig.5-D. The same tendencies can be realized for the intermediate hardness materials of 450 and 500HV. The mechanism of these hardness increase can be said to be due to both strain-aging and Cottrell effect. The reason why as the spring hardness is high, the hardness increase is large, can be assumed that the supersaturated carbon in ferrite due to lower tempering temperature, promotes the strain-aging.

Considering these results, it can be said that the increase of surface hardness caused by warm shot peening be one reason for the improvement of fatigue life.

AN EXAMPLE OF RECENT SPRING APPLICATION WITH 1200 MPA DESIGN STRESS

Considering the advantages of warm shot peening, the coil spring manufacturing lines at NHK's plant employ the warm shot peening as its standard process [5),6)].

To meet with the customer's requirements, with the application of newly developed spring material, UHS1900, see Table3, the coil spring designed by 1200MPa is now under manufacturing.

Table 3. Chemical Contents of UHS 1900 wt%

	C	Si	Mn	Cu
UHS 1900	0.41	1.78	0.20	0.22
	Ni	Cr	V	Ti
	0.34	1.04	0.18	0.07

Fig.6 and Fig.7 show an example of the experimental results, where the fatigue life and residual stress distributions of UHS 1900 spring (warm SP, Design Stress 1200Mpa) are compared with those of SUP7M spring

(SP at RT, 1100MPa). It can be seen from both the Fig.6 and Fig.7, that those experimental results support the considerations and discussions in this paper.

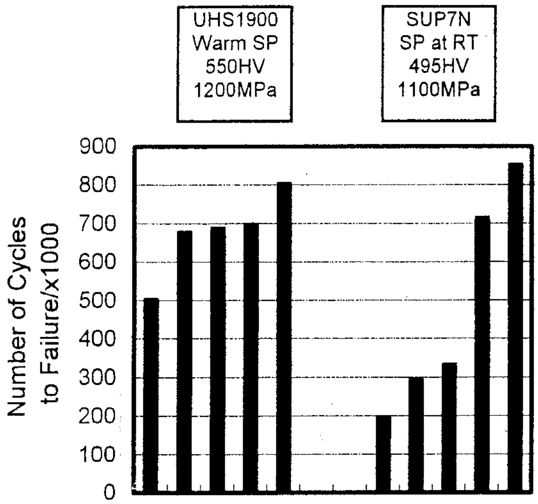

Fig.6 Comparison of fatigue life between UHS1900 and SUP7M

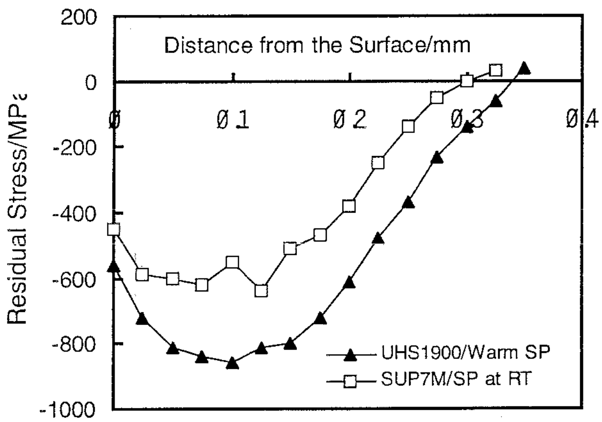

Fig.7 Comparisons of Residual Stress Distributions

CONCLUSIONS

1. The effect of warm shot peening to fatigue life is large for high strengthened(hardness) spring. It is especially more effective when the spring hardness is over the shot hardness.
2. The appropriate temperature of warm shot peening is between 473 and 598K.
3. The main reasons why the warm shot peening is effective to the improvement of fatigue life, are both the increase of compressive residual stress distribution and higher coverage, which can be caused by more effective deformation under warm temperature. The increase of surface hardness by warm shot peening can be said to be an additional reason for the improvement of fatigue life.
4. Since the warm shot peening process can be one of the major manufacturing technology to satisfy the fatigue life and sag-resistance simultaneously, NHK Spring Co.,Ltd have employed this process to its manufacturing line, to meet with 1200MPa coil spring design.

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