

Effect of Surface Heat Treatment on Corrosion-Related Failure of the Suspension Spring

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ABSTRACT

In this research, a new wire material made using surface-reforming heat treatment was developed in order to enhance the corrosion fatigue resistance of suspension springs. The aim of surface reforming is to improve hydrogen embrittlement characteristics through grain refinement and to improve crack propagation resistance by partial softening of hardness.

The grain refinement method used an $\alpha' \rightarrow \gamma$ reversed transformation by rapid short-term heating in repeated induction heating and quenching (R-IHQ) to refine the crystal grain size of SAE 9254 steel spring wire to 4 μm or less.

In order to simultaneously improve the fatigue crack propagation characteristics, the possibility of reducing the hardness immediately below the spring surface layer was also examined. By applying contour hardening in the second IHQ cycle, a heat affected zone (HAZ) is obtained immediately below the surface. Hardness immediately below the surface was reduced a maximum of 25% by making use of the tempering effect of this HAZ.

The corrosion durability life for springs made of wire material produced by the above method was approximately 50% higher than for those made by the conventional method. Greater compactness and lower weight were then successfully achieved by means of high-stress design.

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INTRODUCTION

High-stress design is required to make suspension springs more compact and lighter in weight. Design for higher stress means that spring material must be of higher strength for sag resistance and durability. However, making the material stronger means it will be more susceptible to hydrogen embrittlement, and durability will be lowered by the propagation of fatigue cracks originating at corrosion pits that are caused by snow-melting and other such agents. Therefore the material characteristics of the surface layer portion of the wire from which the springs are made become extremely important. This was conventionally addressed by the method of limiting the susceptibility to failure from corrosion, and was accomplished by developing alloys to which nickel, chrome, titanium, vanadium, molybdenum, and other such elements were added. However, this approach raised issues of multi-purpose usability and material cost.

The development described here used general-purpose steel to produce steel wire for cold-formed spring by subjecting it to surface-reforming heat treatment with a focus on prior austenite crystal grain size in surface layer portions and on hardness distribution. The hydrogen embrittlement characteristics and corrosion fatigue resistance of springs made using that wire material were then evaluated.

Grain refinement is known to be an effective method for improving the hydrogen embrittlement characteristics [1]. Methods of grain refinement that have already been put into practical application. These include the addition of titanium, niobium, molybdenum, and other such alloy elements, and short-term heating of steel wire for cold-formed springs in IHQ as well as other such processes. For the present research, the Grange method was applied with the aim of achieving further grain refinement by using $\alpha' \rightarrow \gamma$ reversed transformation by means of R-IHQ [2, 3].

The crack propagation characteristics of a spring are also closely related to hardness, and it is known that lowering hardness will slow the crack propagation speed [4]. Development therefore applied the $\alpha' \rightarrow \gamma$ reversed transformation treatment described above for contour hardening. The aim was to increase durability by reducing the crack propagation speed by means of the HAZ softening that occurs with contour hardening.

EXPERIMENTAL PROCEDURE

Table 1 shows the chemical composition of the SAE 9254 steel used as the test material.

Table.1. Chemical composition

Material	C	Si	Mn	P	S	Ni	Cu	Cr	Mo
SAE9254	0.56	1.44	0.70	0.007	0.007	0.04	0.03	0.65	0.01

Wire material of 12.6-mm diameter was used for all the test material. As indicated by the surface-reforming heat treatment pattern in Fig. 1, after IHQ heating to a temperature of 1223 K, high-frequency contour hardening was repeated so that the surface was heated to a maximum temperature of 1133 K, after which high-frequency tempering was applied at 743 K.

Comparison material was produced with reference to the heat treatment pattern in Fig. 1, using conventional material without applying a contour hardening process. The contour hardening process had finished very quickly within one second. Values of the distinguished temperatures into wire core were defined as T1, T2, T3, and the layers of microstructures corresponding to these temperatures were also defined as Layer1, Layer2, Layer3 in Fig. 1.

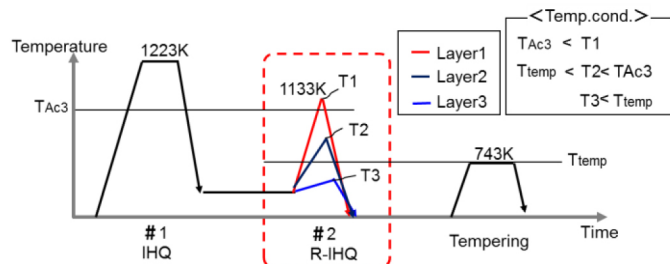


Fig.1. Heat pattern of repeated induction heating and quenching

Observation of the microstructure was carried out by mirror polishing the test material, applying appropriate etching, and examining it under an optical microscope. The prior austenite grain boundary was revealed by etching with a solution of mixed picral and nital. Crystal grain size was measured by the Snyder-Graff method in JISG 0551.

Microstructure in the martensite structure was checked using crystal orientation observation by electron backscatter diffraction (EBSD).

The hardness distribution was measured continuously from the surface layer toward the center using Micro Vickers hardness testing.

Corrosion fatigue testing and delayed failure testing were carried out using coil springs produced by the cold-formed spring manufacturing process, as shown in Fig. 2. The main specifications of the coil springs used for this are shown in Table 2.

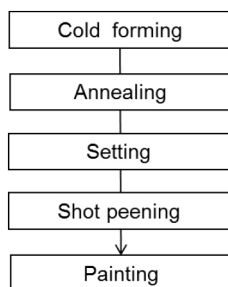


Fig.2. Process of spring manufacturing

Table.2. Dimension of the spring

Wire Diameter (mm)		12.6		
Mean Diameter (mm)		67.6	100.4	67.6
Coil Inside Dia.(mm)		55.0	87.8	55.0
Coil Outside Dia. (mm)		80.2	113.0	80.2
No.of Active Coils		(6.47)		
No.of Total Coils		(7.67)		
Shape End	A	pig tail / flat end		
	B	pig tail / flat end		
Free Height (mm)		355.8		
Solid Height (mm)		89.1		

For corrosion fatigue testing, holes 1 mm in diameter were opened in the coated surface of the coil springs down to the base metal at fixed intervals. These coil springs were subjected to cyclic corrosion testing (CCT) compliant with JASO C604 for four cycles, as shown in Figure 3. The coil springs were then subjected to durability testing by applying excitation force 150,000 times in a vertical direction. This CCT and durability testing were applied in alternation, counting the durability iterations, until the coil spring broke. The durability excitation force was applied under large amplitude conditions with spring shear stress T of 588 ± 300 MPa and under small amplitude conditions with T of 588 ± 126 MPa.

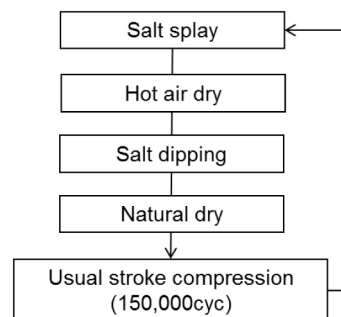


Fig.3. Procedure of corrosion fatigue test

For the delayed fracture testing, uncoated coil springs were compressed to the stroke amount, until their shear stress reached 1274 MPa, then fixed in place using a jig. They were then immersed in 1% diluted sulfuric acid and the time until they broke was measured. The diluted sulfuric acid was replaced at 48-hour intervals.

RESULTS

1. Wire Material Structure and Hardness

Figures 4 and 5 respectively show the macrostructure and the hardness distribution of the wire material cross-section for conventional material and surface-reformed material. Where the conventional material shows a homogeneous structure and hardness distribution, the cross-section of the developed wire material shows a first, second, and third layer forming a three-layered structure.