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54 **High-strength spring steel.**

57 A high-strength spring steel which produces retained austenite less than 10 % in content by weight after quenching in steps of quenching tempering, and has high fatigue strength and relaxation resistance. The steel contains 0.30 to 0.75 % carbon, 1.0 to 4.0 % silicon, 0.5 to 1.5 % manganese, 0.1 to 2.0 % chromium, and 2.0 % or less nickel, all by weight, and iron and unavoidable impurities for the remainder. The steel further contains 0.05 to 0.5 % vanadium and/or 0.05 to 2.0 % molybdenum, as required. Preferably, the retained-austenite content is set to less than 10 % by restricting the carbon, silicon, and nickel contents as follows: $35 \times C (\%) + 2 \times Si (\%) + Ni (\%) < 23 \%$. Preferably, moreover, the oxygen and nitrogen contents of the steel are restricted to 0.0010 % or less and 0.005 % or less, respectively. By doing this, the fatigue strength of the steel can be further improved.

Description**HIGH-STRENGTH SPRING STEEL****BACKGROUND OF THE INVENTION**

5 The present invention relates to a spring steel, and more particularly, to a high-strength spring steel adapted for suspension coil springs of automobiles and the like.

Spring steel is used as a material for valve springs, suspension springs, etc., in internal combustion engines of automobiles and the like. With increase of the demand for lighter, higher-speed versions of engines, therefore, spring steel has come to require higher strength. Thus, there is an increasing demand for the
10 development of high-strength spring steel with satisfactory fatigue strength and relaxation resistance or sag-resistance, in particular.

In general, springs are produced in the following manner, with use of the spring steel of this type. In the case of hot forming, the steel is hot-coiled, quenched, tempered, shot-peened, and preset. In the case of cold forming, the material is quenched and tempered, cold-coiled, shot-peened, and preset. Thus, the steps of
15 quenching and tempering are inevitably included in both cold and hot forming processes. If the amount of additives, such as nickel or other alloying elements, is increased to improve the strength and toughness of the material, retained austenite remains in the structure, thereby exerting a bad influence to the fatigue strength.

The inventors hereof have previously proposed a method for removing the retained austenite (Japanese Provisional Patent Publication No. 60-89553). In the case of cold forming, according to this method, the
20 amount of addition of nickel is increased, and the retained austenite is left intentionally by quenching for higher ductility. After quenching, the material is cold-coiled, taking advantage of the improved ductility. Thereafter, the retained austenite is removed by tempering. Unlike the aforementioned conventional process for manufacturing cold-formed springs, however, this method requires more steps of heat treatment, and therefore, is complicated. Moreover, this method is not applicable to hot spring forming.

SUMMARY OF THE INVENTION

The principal object of the present invention is to provide a high-strength spring steel improved in fatigue strength and relaxation resistance.

Another object of the invention is to provide a high-strength spring steel which can be subjected to both the
30 conventional hot and cold spring forming processes, without requiring any complicated special heat treatment, thus permitting mass production of springs.

The present invention is based on a finding that high-strength spring steel with satisfactory fatigue strength can be obtained by the conventional spring forming process, only if the amount of retained austenite is restricted to less than 10 % after quenching, with use of a properly adjusted chemical composition.

According to the present invention, there is provided a high-strength spring steel which contains 0.30 to 0.75 % carbon, 1.0 to 4.0 % silicon, 0.5 to 1.5 % manganese, 0.1 to 2.0 % chromium, and 2.0 % or less nickel, all by weight, and iron and unavoidable impurities for the remainder. The spring steel further contains 0.05 to 0.5 % vanadium and/or 0.05 to 2.0 % molybdenum, as required. The spring steel of the invention produces
35 retained austenite less than 10 % in content by weight after quenching in steps of quenching and tempering, and has high fatigue strength and relaxation resistance.

Preferably, the retained-austenite content can be easily set to less than 10 % by adjusting the carbon, silicon, and nickel contents as follows:

$$35 \times C (\%) + 2 \times Si (\%) + Ni (\%) < 23 \%$$

Preferably, moreover, the fatigue strength of the steel is further improved by restricting the oxygen and
45 nitrogen contents thereof to 0.0010 % or less and 0.005 % or less, respectively.

The above and other objects, features, and advantages of the invention will be more apparent from the ensuing detailed description taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

50 Fig. 1 is a graph showing the relationship between endurance limit and retained austenite after quenching;

Fig. 2 is a graph prepared by plotting values of shearing creep strain of a steel according to the present invention and sample steels for comparison;

Fig. 3 is a perspective view schematically showing an arrangement of a torsional creep tester of a
55 dead-weight type;

Fig. 4 is a side view showing an outline of a test piece tested by the tester of Fig. 3; and

Fig. 5 is a sectional view taken along line V-V of Fig. 4.

DETAILED DESCRIPTION

60 The following are reasons why the steel according to the present invention is restricted in chemical composition.

Carbon is an effective element for the improvement of the mechanical strength of steel. If the carbon content of steel is less than 0.30 %, however, the material cannot enjoy a necessary strength for a

high-strength spring. If the carbon content exceeds 0.75 %, on the other hand, net-cementite is liable to be produced, so that the fatigue strength of the spring is lowered. Thus, the proper carbon content ranges from 0.30 to 0.75 %.

Silicon tends to be solid-dissolved in ferrite, thereby increasing the strength of the material, and is effective for the improvement of the relaxation resistance of the spring. To attain this, the silicon content must be 1.0 % or more. If it exceeds 4.0 %, however, the toughness of the spring is lowered, and free carbon may possibly be produced by heat treatment. Thus, the proper silicon content ranges from 1.0 to 4.0 %.

Manganese serves not only as a deoxidizing element but also as an effective element for the improvement of hardenability. To attain this, the manganese content must be 0.5 % or more. If it exceeds 1.5 %, however, the hardenability becomes so high that the spring is lowered in toughness and is also deformed in quenching. Thus, the proper manganese content ranges from 0.5 to 1.5 %.

Nickel is an effective element for the improvement of toughness after quenching and tempering. If the nickel content exceeds 2 %, however, too much austenite is retained after quenching, thereby lowering the fatigue strength. Thus, nickel should be added at 2 % or less.

Besides these essential elements, a suitable quantity of vanadium and/or molybdenum may be added as required to improve the spring characteristics. Vanadium, in particular, has a substantial micro-crystallization effect at the time of low-temperature rolling, thus ensuring improved spring characteristics and reliability. Also, vanadium is conducive to precipitation hardening at the time of quenching and tempering. On the other hand, molybdenum is an effective element for the improvement of relaxation resistance. Vanadium and molybdenum are added within content ranges of 0.05 to 0.5 % and 0.05 to 2.0 %, respectively. If the vanadium content exceeds its upper limit, the toughness and spring characteristics are lowered. If the molybdenum content exceeds its upper limit, complex carbide is formed which cannot be dissolved in austenite. If the carbide increases, thus forming a bulky mass, it is as harmful as nonmetallic inclusions, and may possibly lower the fatigue strength.

Unavoidable impurities, including oxygen, nitrogen, etc., should be minimized. Oxygen, in particular, produces oxide-based inclusions, which are liable to be an initiation site of fatigue fracture. Preferably, therefore, the oxygen content is restricted to 0.0010 % or less, by weight. Nitrogen, on the other hand, produces TiN-based inclusions, thereby lowering the fatigue strength, so that the nitrogen content is preferably restricted to 0.005 % or less, by weight.

The spring steel of the chemical composition described above can be formed into springs by the conventional hot or cold spring forming process, including steps of quenching and tempering. In order to obtain high-strength springs having satisfactory spring characteristics, such as fatigue strength, the amount of retained austenite after quenching must be less than 10 %. If the austenite content is less than 10 %, it has no substantial influence on the fatigue strength. A retained-austenite content of 10 % or more may be reduced to less than 10 % by, for example, subjecting the material to sub-zero treatment after quenching. This method is not advisable, however, in view of the simplicity of processes for mass production of springs. Preferably, the carbon, silicon, and nickel contents should be restricted as follows:

$$35 \times C (\%) + 2 \times Si (\%) + Ni (\%) < 23 \%$$

With this arrangement, the amount of retained austenite produced after quenching, in the conventional spring forming processes, can be easily set to lower than 10 %.

Example

A rolled rod of 16 mm $\varnothing$ was manufactured by a conventional method, using a steel of the chemical composition (% by weight) shown in Table 1. Test pieces for tension, relaxation, and fatigue tests were cut out from the rolled rod. They were oil-quenched after being heated at 900 °C for 30 minutes, whereupon the test pieces were tempered at 350 °C for 0.1 hour, and finish-machined. All the test pieces were thermal refined to be adjusted to H_{RC} 55. Table 1 shows test results for the Y-value and endurance limit, and Fig. 2 shows those for the relaxation resistance. Table 1 also shows results of tests on the amount of retained austenite after quenching and the residual shearing strain.

A torsional creep tester of a dead-weight type (max. torque: 25 kgf•m) shown in Fig. 3 was used for the tests on the relaxation resistance. Figs. 4 and 5 show the size and shape of the test pieces used in these tests. The test conditions were as follows:

Test temperature: 80 °C,

Test time: 72 hr,

Applied stress: 110 kgf/mm²,

Shearing prestrain: 0.1 %,

Hardness: H_{RC} 55.

As shown in Fig. 3, the torsional creep tester comprises a test piece holder 2, a loading arm 3, and a dead weight 5 suspended from the distal end of the arm 3. One end of a test piece 10 is fixedly supported by the test piece holder 2, while the other end is fixed to the proximal end of the loading arm 3. The dead weight 5, which has a predetermined weight, is hung down gently from the loading arm 3 by using a jack 6. While keeping this state, the creep strain was measured by means of a dial gage 4. The test pieces were heated by being surrounded by small-sized heating furnaces.

Table 1

No.	Chemical Composition (% by weight)								Y-Value	Retained γ_R after Quenching %	Residual Shearing Quenching	Endurance Limit kgf/mm ²	Remark
	C	Si	Mn	Cr	Ni	V	Mo	(O)	(N)				
1	0.32	2.53	0.81	0.86	0.05	—	—	—	—	3	8.0 x10 ⁻⁴	77	Steel of Invention Steel of Comparison
2a	0.41	2.52	0.82	0.85	1.51	—	—	0.0020	0.0100	7	7.5	75	
2b	0.42	2.51	0.81	0.86	1.52	—	—	0.0006	0.0045	8	7.3	79	
3	0.51	2.01	0.80	0.88	0.52	—	—	—	—	9	7.0	72	
4	0.61	2.00	0.81	0.86	0.55	—	—	—	—	14	6.7	70	
5	0.66	1.50	0.83	0.87	1.01	—	—	—	—	27	6.3	60	
6	0.33	2.51	0.79	0.84	0.03	0.21	—	—	—	7	7.5	83	Steel of Invention Steel of Comparison
7	0.40	2.50	0.81	0.86	1.01	0.23	—	—	—	9	7.1	77	
8	0.51	2.51	0.81	0.87	0.04	0.20	—	—	—	10	6.8	74	
9	0.60	2.50	0.81	0.86	0.05	0.21	—	—	—	15	6.3	66	
10	0.67	2.49	0.82	0.85	0.49	0.22	—	—	—	26	5.9	62	
11	0.31	2.51	0.81	0.86	0.05	—	0.05	—	—	4	7.1	79	Steel of Invention Steel of Comparison
12	0.42	2.49	0.82	0.85	0.49	—	0.5	—	—	8	6.5	80	
13	0.49	2.00	0.80	0.87	0.51	—	1.0	—	—	9	5.8	85	
14	0.61	2.51	0.81	0.86	1.00	—	0.6	—	—	19	5.8	66	
15	0.65	2.50	0.79	0.85	4.03	—	1.5	—	—	31	5.6	65	
16	0.32	3.51	0.80	0.86	0.05	0.21	0.05	—	—	5	8.0	70	Steel of Invention Steel of Comparison
17a	0.41	2.51	0.79	0.86	0.52	0.22	0.5	0.0018	0.0100	4	7.1	84	
17b	0.40	2.52	0.80	0.85	0.51	0.21	0.51	0.0007	0.0050	6	7.2	88	
18	0.52	2.52	0.81	0.87	3.98	0.20	1.0	—	—	8	6.2	85	
19	0.56	1.01	0.82	0.85	0.51	0.21	1.5	—	—	10	4.8	81	
20	0.61	2.51	0.81	0.85	1.50	0.21	1.01	—	—	23	4.5	64	

Fig. 1 is a graph showing, by plotting, the relationship between the endurance shown in Table 1 and the amount of retained austenite γ_R after quenching. As seen from Fig. 1, the endurance limit is reduced

considerably when the amount of retained austenite reaches 10 % or more. All of sample steels according to the present invention exhibited a retained-austenite content of less than 10 %, thus ensuring satisfactory fatigue strength. The relationship between the endurance limit and the content ratios of different impurities, i.e., oxygen and nitrogen, was examined for some of the sample steels. Sample No. 2a, which contains 0.0020 % oxygen and 0.0100 % nitrogen, as shown in Table 1, exhibited a endurance limit of 75 kgf/mm², while Sample No. 2b, which contains 0.0006 % oxygen and 0.0045 % nitrogen, exhibited an improved endurance limit of 79 kgf/mm². Likewise, Sample No. 17a, which contains 0.0018 % oxygen and 0.0100 % nitrogen, as shown in Table 1, exhibited a endurance limit of 84 kgf/mm², while Sample No. 17b, which contains 0.0007 % oxygen and 0.0050 % nitrogen, exhibited an improved endurance limit of 88 kgf/mm².

The design of suspension springs depends considerably on their relaxation resistance. In particular, the warm relaxation resistance of the suspension springs has recently become the object of public attention. Thereupon, a torsional creep test was conducted under the aforementioned conditions. As shown in Table 1 and Figure 2, the steel according to the present invention proved much superior to the currently used material, JIS SUP 7 (equivalent to AISI 9260), in shearing creep strain after 72 hours of testing and in relaxation resistance.

Claims

1. A high strength spring steel having high fatigue strength and relaxation resistance, which is made to contain less than 10% by weight of retained austenite by quenching in a quenching/tempering step, said steel containing 0.30 to 0.75 % carbon, 1.0 to 4.0 % silicon, 0.5 to 1.5 % manganese, 0.1 to 2.0 % chromium, and 2.0 % or less nickel, all by weight, the remainder being iron and incidental impurities.

2. A high strength spring steel according to claim 1, which is made to contain less than 10% by weight of retained austenite by restricting the carbon, silicon, and nickel contents as follows:

$$35 \times C (\%) + 2 \times Si (\%) + Ni (\%) \leq 23 \%$$

3. A high strength spring steel according to claim 1, further containing 0.05 to 0.5 % vanadium and/or 0.05 to 2.0 % molybdenum, by weight.

4. A high strength spring steel according to claim 1, wherein the oxygen content of said steel is restricted to 0.0010 % or less, by weight.

5. A high strength spring steel according to claim 1, wherein the nitrogen content of said steel is restricted to 0.005 % or less, by weight.

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Fig.1

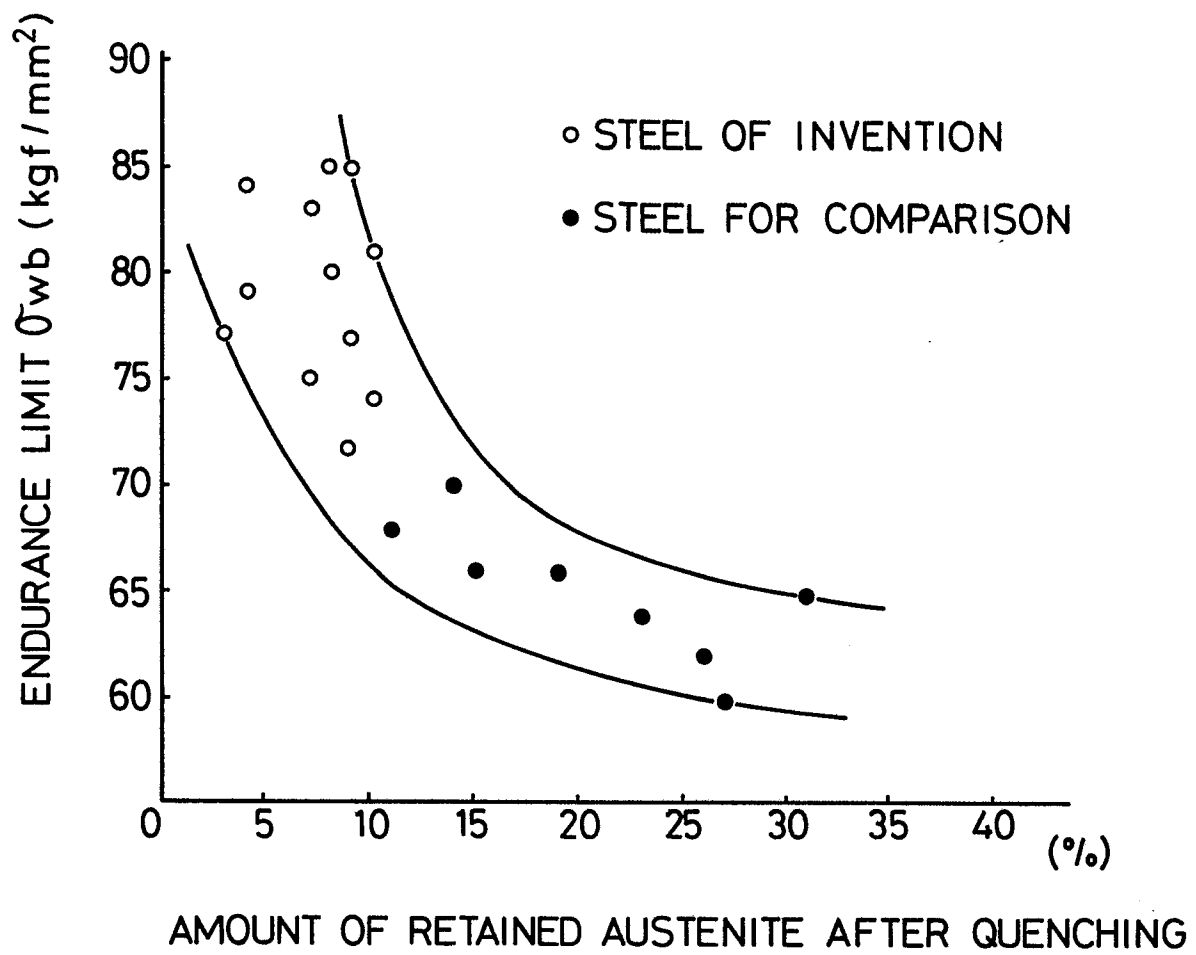
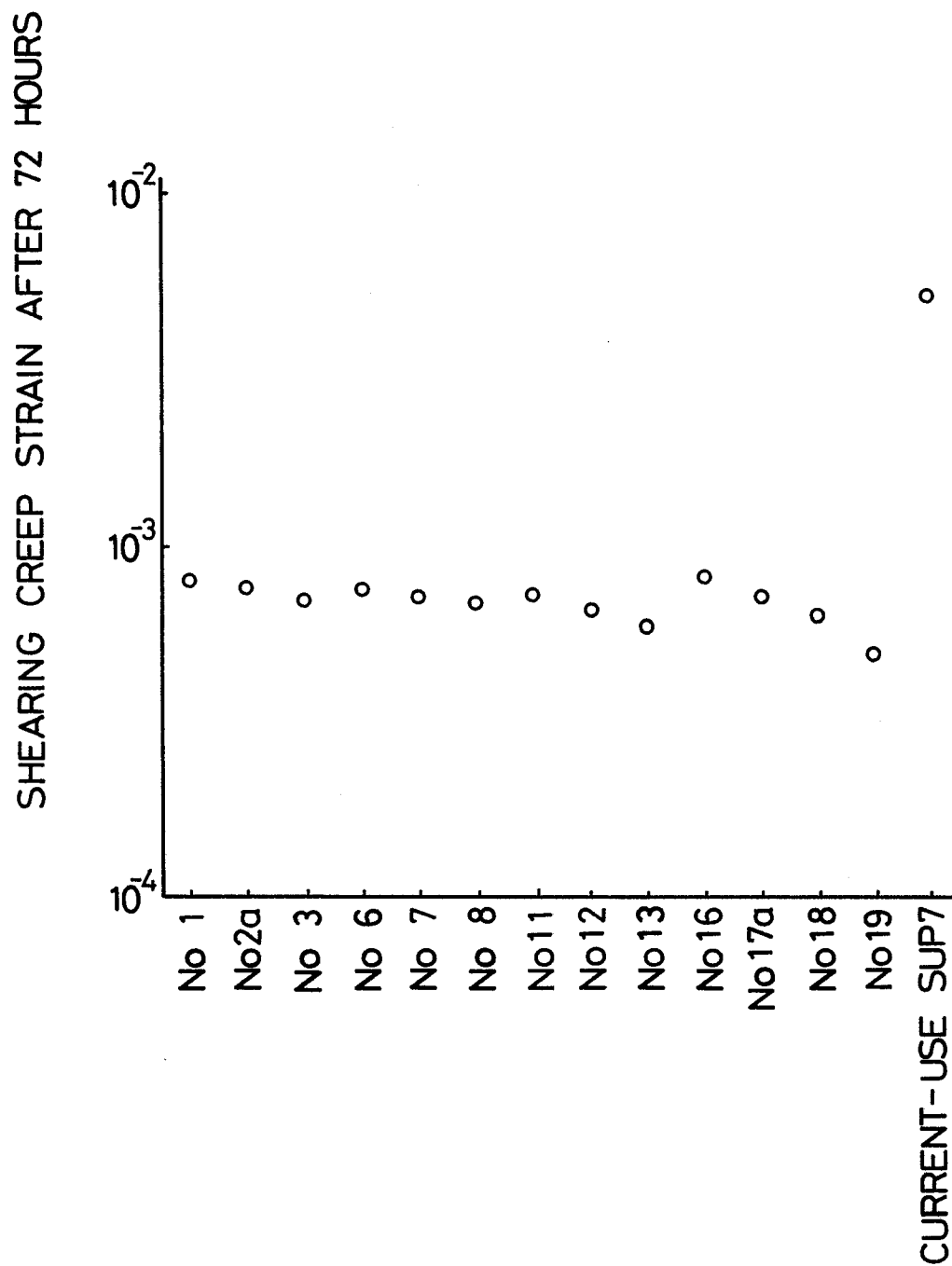


Fig.2



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Fig.3

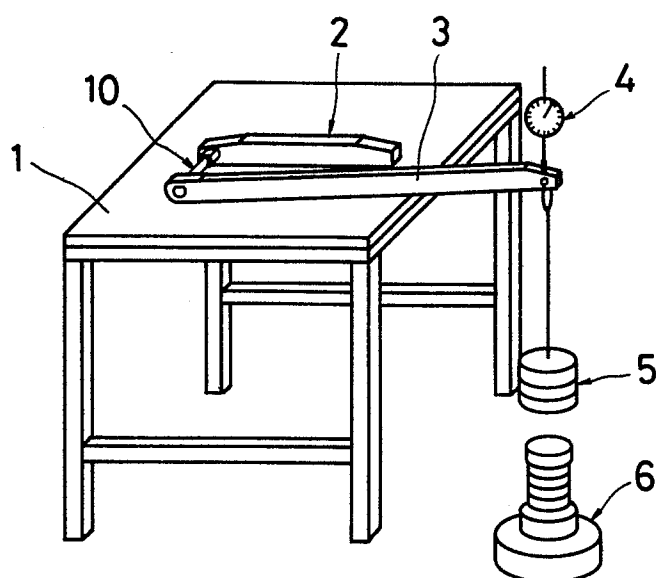


Fig.4

Fig.5

