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CHA et al.(10) **Pub. No.: US 2017/0362688 A1**(43) **Pub. Date: Dec. 21, 2017**(54) **HIGH-STRENGTH SPRING STEEL HAVING
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38/002 (2013.01); *C22C 38/42* (2013.01)(73) Assignee: **Hyundai Motor Company**, Seoul (KR)(21) Appl. No.: **15/345,112**(22) Filed: **Nov. 7, 2016**(30) **Foreign Application Priority Data**

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(57)

ABSTRACT

A high-strength spring steel coil spring of a vehicle suspension, having excellent corrosion resistance, may include 0.4 to 0.9 wt % of C, 0.9 to 2.3 wt % of Si, 0.5 to 1.2 wt % of Mn, 0.6 to 1.5 wt % of Cr, 0.01 to 0.5 wt % of Mo, 0.01 to 0.9 wt % of Ni, 0.5 wt % or less (excluding 0 wt %) of V, 0.5 wt % or less (excluding 0 wt %) of Nb, 0.3 wt % or less (excluding 0 wt %) of Ti, 1.0 wt % or less (excluding 0 wt %) of Co, 0.1 wt % or less (excluding 0 wt %) of B, 0.3 wt % or less (excluding 0 wt %) of W, 0.3 wt % or less (excluding 0 wt %) of Cu, 0.3 wt % or less (excluding 0 wt %) of Al, 0.03 wt % or less (excluding 0 wt %) of N, 0.003 wt % or less (excluding 0 wt %) of O, and a remainder of Fe and inevitable impurities.

wt. %	C	Si	Mn	Cr	Mo	Ni	V	Nb	Ti	Co	B	W	Cu	Al	N	O
Conventional steel (SUJPM12C)	0.55	1.45	0.68	0.71	-	0.23	0.08	-	0.03	-	-	-	0.23	0.035	-	-
Example 1	0.58	0.92	0.53	0.91	0.11	0.45	0.21	0.04	0.005	0.34	0.017	0.014	0.053	0.089	0.0011	0.0009
Example 2	0.42	2.28	1.17	0.61	0.34	0.03	0.48	0.29	0.027	0.97	0.004	0.18	0.062	0.014	0.0009	0.0011
Example 3	0.86	1.72	0.85	1.46	0.48	0.88	0.04	0.49	0.29	0.57	0.012	0.07	0.046	0.013	0.0014	0.0013
Comp. Example 1	0.53	1.74	0.73	0.57	0.16	0.35	0.45	0.45	0.07	0.29	0.083	0.18	0.041	0.006	0.0013	0.0008
Comp. Example 2	0.81	1.81	1.01	1.52	0.046	0.036	0.035	0.075	0.21	0.96	0.068	0.15	0.04	0.017	0.0014	0.0007
Comp. Example 3	0.57	1.53	0.66	0.91	0.009	0.38	0.14	0.07	0.08	0.05	0.015	0.07	0.052	0.006	0.0012	0.0003
Comp. Example 4	0.65	2.21	0.78	0.71	0.51	0.72	0.18	0.25	0.17	0.93	0.003	0.17	0.034	0.011	0.0011	0.0006
Comp. Example 5	0.82	1.83	1.19	1.25	0.35	0.92	0.44	0.47	0.25	0.47	0.005	0.056	0.04	0.015	0.0012	0.0011
Comp. Example 6	0.53	1.54	0.63	0.86	0.013	0.008	0.35	0.09	0.28	0.76	0.066	0.088	0.053	0.009	0.0013	0.0007
Comp. Example 7	0.65	2.15	0.72	0.71	0.36	0.57	0.51	0.27	0.16	0.77	0.086	0.13	0.065	0.014	0.0015	0.0008
Comp. Example 8	0.82	1.63	1.16	1.14	0.47	0.84	0.53	0.46	0.27	0.53	0.069	0.12	0.045	0.013	0.0014	0.0006
Comp. Example 9	0.67	2.23	0.73	0.78	0.16	0.88	0.46	0.52	0.08	0.82	0.029	0.13	0.044	0.008	0.0013	0.0009
Comp. Example 10	0.81	1.84	1.18	1.46	0.36	0.76	0.16	0.51	0.26	0.63	0.008	0.045	0.053	0.017	0.0015	0.0014
Comp. Example 11	0.72	1.64	1.12	1.15	0.42	0.83	0.31	0.25	0.32	0.95	0.055	0.08	0.061	0.013	0.0016	0.0012
Comp. Example 12	0.65	2.25	0.76	0.74	0.15	0.74	0.25	0.19	0.33	0.94	0.015	0.037	0.042	0.004	0.001	0.0003
Comp. Example 13	0.62	1.48	0.86	0.75	0.016	0.38	0.47	0.46	0.08	1.01	0.063	0.026	0.063	0.015	0.0014	0.0016
Comp. Example 14	0.64	1.83	1.19	1.34	0.36	0.71	0.36	0.08	0.17	1.02	0.038	0.15	0.06	0.016	0.0013	0.0011
Comp. Example 15	0.55	1.9	0.91	0.89	0.013	0.46	0.46	0.27	0.15	0.42	0.19	0.14	0.047	0.009	0.001	0.0007
Comp. Example 16	0.51	1.62	0.74	0.71	0.36	0.72	0.41	0.15	0.25	0.83	0.11	0.067	0.053	0.014	0.0013	0.0008
Comp. Example 17	0.63	1.45	0.83	0.93	0.48	0.75	0.03	0.23	0.26	0.61	0.009	0.33	0.027	0.008	0.0018	0.0013
Comp. Example 18	0.65	1.8	1.22	1.29	0.38	0.83	0.47	0.37	0.09	0.38	0.069	0.31	0.042	0.011	0.0019	0.0011

FIG. 1

wt %	C	Si	Mn	Cr	Mo	Ni	V	Nb	T	Co	B	W	Cu	Al	N	O
Conventional steel (SUPM12C)	0.55	1.45	0.68	0.71	-	0.23	0.08	-	0.03	-	-		0.23	0.035	-	-
Example 1	0.58	0.92	0.53	0.91	0.11	0.45	0.21	0.04	0.005	0.04	0.017	0.014	0.053	0.089	0.0011	0.0003
Example 2	0.42	2.28	1.17	0.61	0.34	0.03	0.48	0.29	0.027	0.97	0.004	0.18	0.062	0.014	0.0009	0.0011
Example 3	0.86	1.72	0.85	1.46	0.48	0.88	0.04	0.49	0.29	0.57	0.012	0.07	0.046	0.013	0.0014	0.0015
Comp. Example 1	0.53	1.74	0.73	0.57	0.16	0.35	0.45	0.45	0.07	0.09	0.083	0.18	0.041	0.006	0.0013	0.0008
Comp. Example 2	0.81	1.81	1.01	1.52	0.046	0.056	0.035	0.025	0.21	0.96	0.068	0.15	0.04	0.017	0.0014	0.0007
Comp. Example 3	0.57	1.53	0.66	0.91	0.009	0.38	0.14	0.07	0.08	0.05	0.015	0.07	0.052	0.006	0.0012	0.0005
Comp. Example 4	0.65	2.21	0.78	0.71	0.51	0.72	0.18	0.25	0.17	0.93	0.003	0.17	0.034	0.011	0.0011	0.0006
Comp. Example 5	0.82	1.83	1.19	1.25	0.35	0.92	0.44	0.47	0.25	0.47	0.005	0.056	0.04	0.015	0.0012	0.0011
Comp. Example 6	0.53	1.54	0.63	0.86	0.013	0.008	0.35	0.09	0.28	0.76	0.066	0.088	0.053	0.009	0.0013	0.0007
Comp. Example 7	0.65	2.15	0.72	0.74	0.36	0.37	0.51	0.24	0.16	0.17	0.086	0.13	0.065	0.014	0.0015	0.0008
Comp. Example 8	0.82	1.63	1.16	1.14	0.47	0.84	0.53	0.46	0.27	0.53	0.069	0.12	0.045	0.013	0.0014	0.0006
Comp. Example 9	0.67	2.23	0.73	0.78	0.16	0.88	0.46	0.52	0.08	0.82	0.029	0.13	0.044	0.008	0.0013	0.0009
Comp. Example 10	0.81	1.84	1.18	1.46	0.36	0.76	0.16	0.51	0.26	0.83	0.008	0.045	0.053	0.017	0.0015	0.0014
Comp. Example 11	0.72	1.64	1.12	1.15	0.42	0.83	0.31	0.25	0.32	0.95	0.055	0.08	0.061	0.013	0.0016	0.0012
Comp. Example 12	0.65	2.25	0.76	0.74	0.15	0.74	0.25	0.19	0.33	0.94	0.015	0.037	0.042	0.004	0.001	0.0005
Comp. Example 13	0.62	1.48	0.86	0.75	0.016	0.38	0.47	0.46	0.08	1.01	0.063	0.026	0.063	0.015	0.0014	0.0016
Comp. Example 14	0.64	1.83	1.19	1.34	0.36	0.71	0.36	0.08	0.17	1.02	0.038	0.15	0.06	0.016	0.0013	0.0011
Comp. Example 15	0.55	1.9	0.91	0.99	0.013	0.46	0.46	0.27	0.15	0.42	0.19	0.14	0.047	0.009	0.001	0.0007
Comp. Example 16	0.51	1.62	0.74	0.71	0.36	0.72	0.41	0.15	0.25	0.83	0.11	0.067	0.053	0.014	0.0013	0.0008
Comp. Example 17	0.63	1.45	0.83	0.93	0.48	0.75	0.03	0.23	0.26	0.61	0.009	0.33	0.027	0.008	0.0018	0.0015
Comp. Example 18	0.65	1.8	1.22	1.29	0.38	0.83	0.47	0.37	0.09	0.08	0.069	0.31	0.042	0.011	0.0019	0.001

FIG. 2

Classification	Tensile strength (MPa)	Hardness (HV)	Wire fatigue life	pit depth, μm	Component corrosion fatigue life (Salt)	Cyclic corrosion fatigue life (ES Cyclic)	Proportion of cementite <9% Proportion of carbide >3% Proportion of boride >0.01%
Conventional steel (SUSPW12C)	22	23 ten thousand times	1.8 ten thousand times	27.9 ten thousand times	573	1965	X
Example 1	10	32.9 ten thousand times	3.3 ten thousand times	41.5 ten thousand times	737	2217	O
Example 2	12	34.8 ten thousand times	3.0 ten thousand times	42.2 ten thousand times	737	2232	O
Example 3	11	35.1 ten thousand times	3.2 ten thousand times	44.2 ten thousand times	749	2218	O
Comp. Example 1	24	29 ten thousand times	1.7 ten thousand times	26.6 ten thousand times	584	1920	X
Comp. Example 2	13	31 ten thousand times	2.8 ten thousand times	25.5 ten thousand times	687	2183	O
Comp. Example 3	22	17 ten thousand times	1.6 ten thousand times	25.2 ten thousand times	612	1864	X
Comp. Example 4	14	26 ten thousand times	2.6 ten thousand times	23.5 ten thousand times	682	2202	O
Comp. Example 5	12	25 ten thousand times	2.8 ten thousand times	24.8 ten thousand times	638	2015	O
Comp. Example 6	26	24 ten thousand times	1.9 ten thousand times	22.2 ten thousand times	628	2010	O
Comp. Example 7	25	22 ten thousand times	2.3 ten thousand times	26.3 ten thousand times	685	2181	O
Comp. Example 8	24	21 ten thousand times	2.2 ten thousand times	26.5 ten thousand times	686	2182	O
Comp. Example 9	23	23 ten thousand times	2.4 ten thousand times	27.3 ten thousand times	688	2186	X
Comp. Example 10	24	21 ten thousand times	2.3 ten thousand times	26.5 ten thousand times	686	2182	X
Comp. Example 11	25	28 ten thousand times	1.7 ten thousand times	23.1 ten thousand times	590	1935	X
Comp. Example 12	25	27 ten thousand times	1.5 ten thousand times	24.3 ten thousand times	595	1952	X
Comp. Example 13	21	23 ten thousand times	1.9 ten thousand times	27.9 ten thousand times	623	2025	O
Comp. Example 14	22	22 ten thousand times	1.8 ten thousand times	27.1 ten thousand times	636	2035	O
Comp. Example 15	28	26 ten thousand times	2.6 ten thousand times	27.6 ten thousand times	631	2055	O
Comp. Example 16	27	27 ten thousand times	2.5 ten thousand times	28.3 ten thousand times	625	2045	O
Comp. Example 17	23	27 ten thousand times	2.9 ten thousand times	31.2 ten thousand times	681	2198	X
Comp. Example 18	24	26 ten thousand times	2.8 ten thousand times	31.6 ten thousand times	683	2201	X

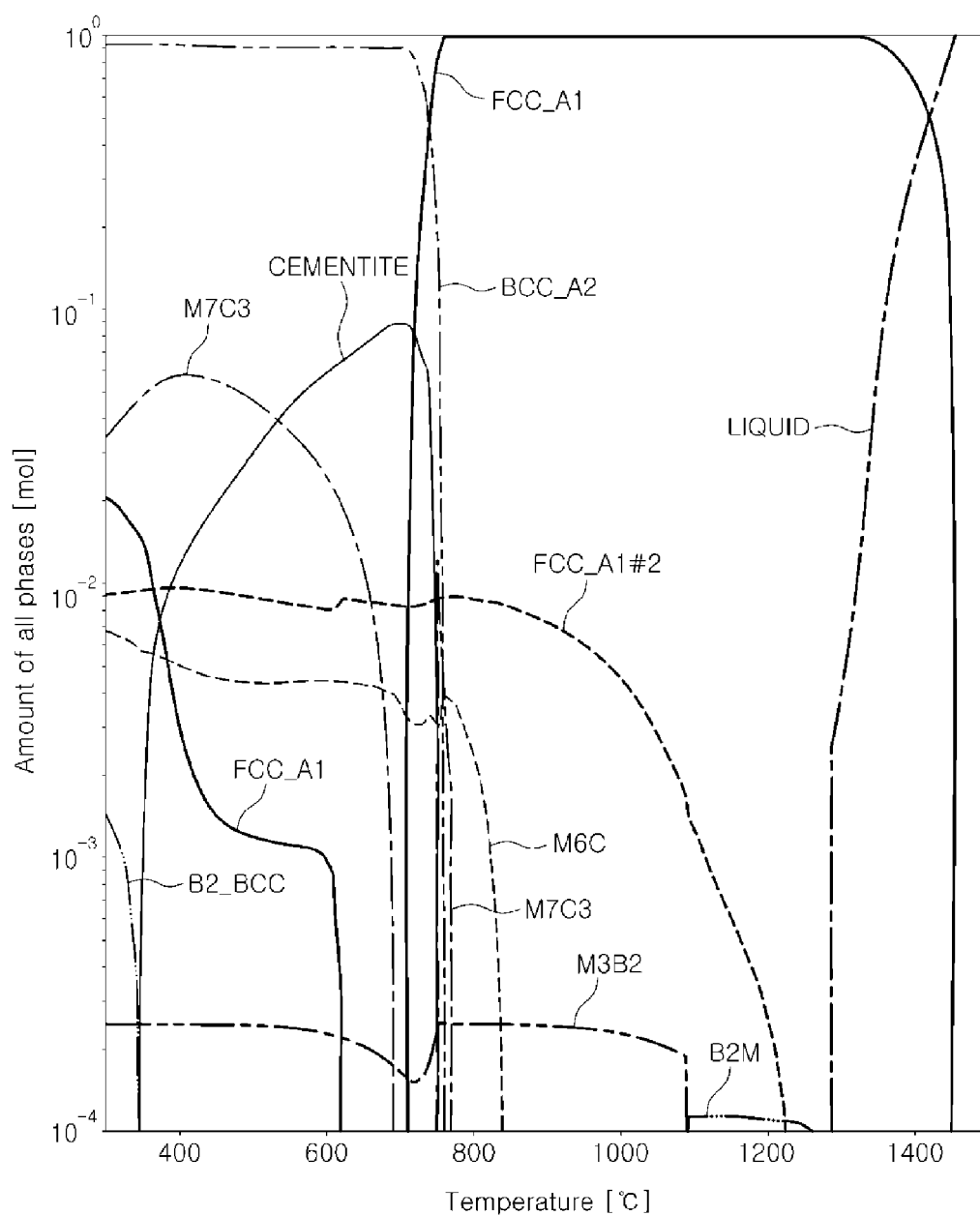


FIG. 3

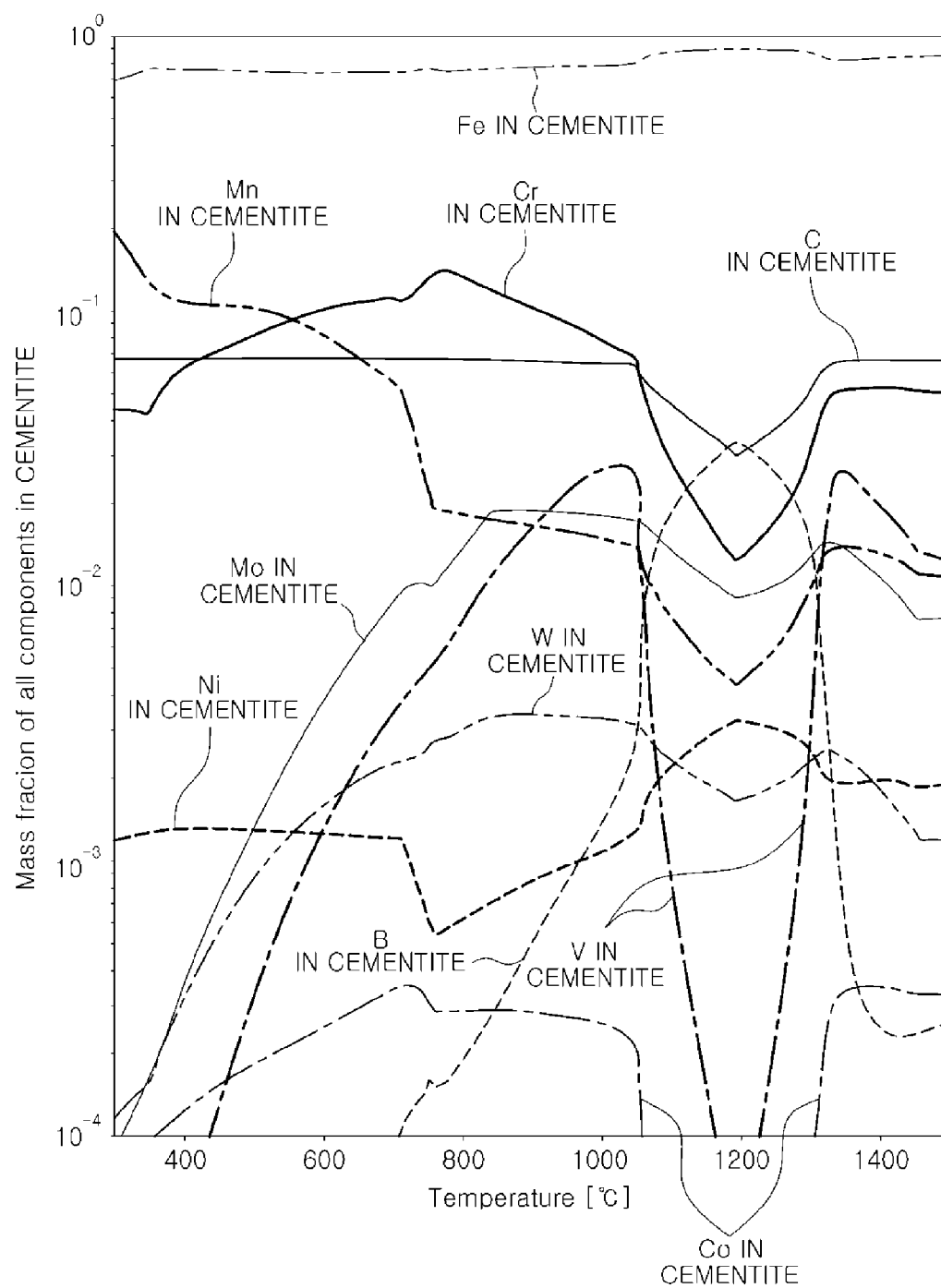


FIG. 4

HIGH-STRENGTH SPRING STEEL HAVING EXCELLENT CORROSION RESISTANCE

CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to Korean Patent Application No. 10-2016-0076981, filed Jun. 21, 2016, the entire content of which is incorporated herein for all purposes by this reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to high-strength spring steel having excellent corrosion resistance and, more particularly, to high-strength spring steel having excellent corrosion resistance, which is increased in tensile strength and fatigue life so as to be suitable for use in a vehicle suspension.

Description of Related Art

[0003] Spring steel has to be imparted with high fatigue strength in order to be suitable for use as a spring for a vehicle suspension.

[0004] With the recent goal of reducing the emission of exhaust gas or increasing fuel efficiency, the demand for lightweight-ness of vehicles or high output thereof is increasing, and thus, a coil spring for use in an engine or a suspension must be designed to withstand high stress.

[0005] In particular, a coil spring for a vehicle suspension has to possess high strength because it must endure a continuous load, and is required to have corrosion resistance because it is used in a state of being exposed to the external environment.

[0006] Such a coil spring for use in a suspension is composed mainly of Carbon (C), Silicone (Si), Manganese (Mn), Chromium (Cr) and the like, thereby assuring spring steel having a tensile strength of about 1900 Mpa and a certain amount of corrosion resistance. Moreover, as the kind and amount of alloy elements are adjusted, attempts are being made to control inclusions that are able to further increase fatigue life.

[0007] The information disclosed in this Background of the Invention section is only for enhancement of understanding of the general background of the invention and should not be taken as an acknowledgement or any form of suggestion that this information forms the prior art already known to a person skilled in the art.

BRIEF SUMMARY

[0008] Various aspects of the present invention are directed to providing a high-strength spring steel having excellent corrosion resistance, wherein the amounts of Cr, Mo, Ni, V, Nb, Ti, Co, B and W are optimized, thereby controlling inclusions that increase fatigue life in a corrosive environment while ensuring high tensile strength.

[0009] According to various aspects of the present invention, a high-strength spring steel having excellent corrosion resistance, suitable for use as steel for a coil spring of a vehicle suspension, may include 0.4 to 0.9 wt % of Carbon (C), 0.9 to 2.3 wt % of Silicon (Si), 0.5 to 1.2 wt % of Manganese (Mn), 0.6 to 1.5 wt % of Chromium (Cr), 0.01 to 0.5 wt % of Molybdenum (Mo), 0.01 to 0.9 wt % of

Nickel (Ni), 0.5 wt % or less (excluding 0 wt %) of Vanadium (V), 0.5 wt % or less (excluding 0 wt %) of Niobium (Nb), 0.3 wt % or less (excluding 0 wt %) of Titanium (Ti), 1.0 wt % or less (excluding 0 wt %) of Cobalt (Co), 0.1 wt % or less (excluding 0 wt %) of Boron (B), 0.3 wt % or less (excluding 0 wt %) of Tungsten (W), 0.3 wt % or less (excluding 0 wt %) of Copper (Cu), 0.3 wt % or less (excluding 0 wt %) of Aluminum (Al), 0.03 wt % or less (excluding 0 wt %) of Nitrogen (N), 0.003 wt % or less (excluding 0 wt %) of Oxygen (O), and a remainder of Iron (Fe) and inevitable impurities.

[0010] The spring steel may have a tensile strength of 2200 MPa or more.

[0011] The spring steel may have a hardness of 700 HV or more.

[0012] The spring steel may have a pit depth of 20 μ m or less.

[0013] The spring steel may endure a bending fatigue test at least 320 thousand times.

[0014] The spring steel may endure a component corrosion fatigue life test at least 30 thousand times.

[0015] The spring steel may endure a cyclic corrosion fatigue life test at least 400 thousand times.

[0016] According to various embodiments of the present invention, high-strength spring steel having excellent corrosion resistance can be obtained in a manner of optimizing the amounts of main alloy elements, thus attaining a high tensile strength of 2200 MPa or more and the refinement of inclusions to thereby increase corrosion resistance and cyclic corrosion fatigue life by 40 to 50%.

[0017] It is understood that the term “vehicle” or “vehicular” or other similar terms as used herein is inclusive of motor vehicles in general such as passenger automobiles including sports utility vehicles (SUV), buses, trucks, various commercial vehicles, watercraft including a variety of boats and ships, aircraft, and the like, and includes hybrid vehicles, electric vehicles, plug-in hybrid electric vehicles, hydrogen-powered vehicles and other alternative fuel vehicles (e.g., fuel derived from resources other than petroleum). As referred to herein, a hybrid vehicle is a vehicle that has two or more sources of power, for example, both gasoline-powered and electric-powered vehicles.

[0018] The methods and apparatuses of the present invention have other features and advantages which will be apparent from or are set forth in more detail in the accompanying drawings, which are incorporated herein, and the following Detailed Description, which together serve to explain certain principles of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 is a table showing the elements of Examples and Comparative Examples.

[0020] FIG. 2 is a table showing the properties and performance of Examples and Comparative Examples.

[0021] FIG. 3 is a graph showing the results of calculation of phase transformation at different temperatures of spring steel according to various embodiments of the present invention.

[0022] FIG. 4 is a graph showing the results of calculation of phase transformation at different temperatures in the cementite tissue of the spring steel according to various embodiments of the present invention.

[0023] It should be understood that the appended drawings are not necessarily to scale, presenting a somewhat simpli-

fied representation of various features illustrative of the basic principles of the invention. The specific design features of the present invention as disclosed herein, including, for example, specific dimensions, orientations, locations, and shapes will be determined in part by the particular intended application and use environment.

DETAILED DESCRIPTION

[0024] Reference will now be made in detail to various embodiments of the present invention(s), examples of which are illustrated in the accompanying drawings and described below. While the invention(s) will be described in conjunction with exemplary embodiments, it will be understood that the present description is not intended to limit the invention(s) to those exemplary embodiments. On the contrary, the invention(s) is/are intended to cover not only the exemplary embodiments, but also various alternatives, modifications, equivalents and other embodiments, which may be included within the spirit and scope of the invention as defined by the appended claims.

[0025] FIG. 1 is a table showing the elements of Examples and Comparative Examples, and FIG. 2 is a table showing the properties and performance of Examples and Comparative Examples.

[0026] According to various embodiments of the present invention, high-strength spring steel having excellent corrosion resistance is steel for use in a coil spring for a vehicle suspension, and is configured such that the amounts of main alloy elements are optimized, thus enhancing properties such as tensile strength and fatigue life. Specifically, the spring steel includes 0.4 to 0.9 wt % of C, 0.9 to 2.3 wt % of Si, 0.5 to 1.2 wt % of Mn, 0.6 to 1.5 wt % of Cr, 0.01 to 0.5 wt % of Mo, 0.01 to 0.9 wt % of Ni, 0.5 wt % or less (excluding 0 wt %) of V, 0.5 wt % or less (excluding 0 wt %) of Nb, 0.3 wt % or less (excluding 0 wt %) of Ti, 1.0 wt % or less (excluding 0 wt %) of Co, 0.1 wt % or less (excluding 0 wt %) of B, 0.3 wt % or less (excluding 0 wt %) of W, 0.3 wt % or less (excluding 0 wt %) of Cu, 0.3 wt % or less (excluding 0 wt %) of Al, 0.03 wt % or less (excluding 0 wt %) of N, 0.003 wt % or less (excluding 0 wt %) of O, and the remainder of Fe and other inevitable impurities.

[0027] In various embodiments of the present invention, the reason why the alloy elements and the amounts thereof are limited is as follows. Unless otherwise mentioned, %, when used as a unit indicating an amount, indicates weight percentage (wt %).

[0028] In various embodiments, Carbon (C) is contained in an amount of 0.4 to 0.9%. In steel, the amount of carbon is proportional to increased strength. If the amount of carbon is less than 0.4%, the increase in strength is insignificant due to the insufficient hardenability upon heat treatment. On the other hand, if the amount thereof exceeds 0.9%, martensite tissue may be formed upon quenching, thus deteriorating fatigue strength and lowering toughness. Given the above range, high strength and softness may both be ensured.

[0029] In various embodiments, Silicon (Si) is contained in an amount of 0.9 to 2.3%. Si functions to increase strength and temper softening resistance due to the solid solution thereof in ferrite. If the amount of Si is less than 0.9%, temper softening resistance may decrease. On the other hand, if the amount thereof exceeds 2.3%, decarbonization may occur upon heat treatment.

[0030] In various embodiments, Manganese (Mn) is contained in an amount of 0.5 to 1.2%. Mn functions to increase bending fatigue strength and hardenability due to the solid solution thereof in a matrix. If the amount of Mn is less than 0.5%, it is difficult to ensure hardenability. On the other hand, if the amount thereof exceeds 1.2%, toughness may decrease.

[0031] In some embodiments, Chromium (Cr) is contained in an amount of 0.6 to 1.5%. Cr functions to increase strength, tempering resistance and dimensional stability, is dissolved in austenite, forms CrC precipitates upon tempering, improves hardenability, and suppresses softening, thus increasing strength and contributing to grain refinement and toughness enhancement. If the amount of Cr is less than 0.6%, corrosion resistance and pitting corrosion may deteriorate. On the other hand, if the amount thereof exceeds 1.5%, the production of other carbides is suppressed and cost-related issues may arise.

[0032] In some embodiments, Molybdenum (Mo) is contained in an amount of 0.01 to 0.5%. Mo functions to form finely precipitated carbide like Cr, thus increasing strength and fracture toughness. In particular, 1 to 5 nm TiMoC is uniformly formed, whereby tempering resistance may be increased and heat resistance and high strength may be assured. If the amount of Mo is less than 0.01%, carbide cannot be formed, making it difficult to ensure sufficient strength and pitting corrosion. On the other hand, if the amount thereof exceeds 0.5%, processability and productivity may decrease and the effects of precipitation and strength enhancement may become saturated, and thus there is no need to use an excess of Mo in terms of cost.

[0033] In some embodiments, Nickel (Ni) is contained in an amount of 0.01 to 0.9%. Ni aids in increasing corrosion resistance and functions to increase heat resistance, prevent low-temperature brittleness, and increase hardenability, dimensional stability and setability. If the amount of Ni is less than 0.01%, corrosion resistance and high-temperature stability may deteriorate. On the other hand, if the amount thereof exceeds 0.9%, red brittleness may occur.

[0034] In some embodiments, Vanadium (V) is contained in an amount of 0.5% or less (excluding 0%). V functions to increase tissue refinement, tempering resistance, dimensional stability and setability and to ensure heat resistance and high strength, and may form a fine precipitate, namely VC precipitate, to thus enhance fracture toughness. In particular, the fine precipitate VC inhibits grain boundary movement, and V forms a solid solution upon austenization and is precipitated upon tempering to thus cause secondary hardening. If the amount of V exceeds 0.5%, the size of the precipitate becomes large and hardness may decrease after quenching.

[0035] In some embodiments, Niobium (Nb) is contained in an amount of 0.5% or less (excluding 0%). Nb makes the tissue fine, and is responsible for hardening the steel surface via nitridation and increasing dimensional stability and setability. Furthermore, Nb is formed into NbC to increase strength, and controls the rate of production of other carbides (CrC, VC, TiC, MoC). If the amount of Nb exceeds 0.5%, the production of other carbides is suppressed and the formation of VC is increased, which is undesirable.

[0036] In some embodiments, Titanium (Ti) is contained in an amount of 0.3% or less (excluding 0%). Ti prevents the recrystallization of grains and suppresses the growth thereof, like Nb, Al, etc. Furthermore, Ti is formed into nano

carbides, such as TiC, TiMoC and the like, and reacts with nitrogen (N) to form TiN so as to inhibit the growth of grains. Also, TiB₂ is formed, thus preventing the coupling of B with N, thereby minimizing the reduction in the hardenability of BN. If the amount of Ti exceeds 0.3%, the functions of other alloy elements may deteriorate, and high costs may result.

[0037] In various embodiments, Cobalt (Co) is contained in an amount of 0.3% or less (excluding 0%). Co increases processability and forms fine carbides. In particular, the growth of grains is inhibited at high temperatures, and hardenability, strength and temperature stability may increase. If the amount of Co exceeds 0.3%, the functions of other alloy elements may deteriorate, and high costs may result.

[0038] In various embodiments, Boron (B) is contained in an amount of 0.1% or less (excluding 0%). B plays a role in increasing tensile strength and elongation, preventing corrosion, and increasing corrosion resistance and impact resistance. If the amount of B exceeds 0.1%, toughness and softness may decrease, and thus impact resistance may decrease and fatigue life may be shortened, which is undesirable.

[0039] In various embodiments, Tungsten (W) is contained in an amount of 0.3% or less (excluding 0%). W is formed into a carbide precipitate to thus increase high-temperature wear resistance and toughness, inhibit the growth of tissue, and decrease scale resistance. If the amount of W exceeds 0.3%, WC is excessively formed, and thus low toughness may result.

[0040] In various embodiments, Copper (Cu) is contained in an amount of 0.3% or less (excluding 0%). Cu is used to increase quenchability and strength after tempering and to increase the corrosion resistance of steel, like Ni. However, if excess Cu is contained, alloying costs may increase. Hence, the amount of Cu is limited to 0.3% or less.

[0041] In various embodiments, Aluminum (Al) is contained in an amount of 0.3% or less (excluding 0%). Al may be formed into AlN through the reaction with N, whereby austenite is made fine and strength and impact toughness are increased. In particular, Al is added together with Nb, Ti and Mo, thereby decreasing the amount of the element V, which is expensive, for ensuring grain refinement and the amount of the element Ni, which is also expensive, for ensuring toughness. However, when excess Al is contained in the steel, the steel may be weakened. Hence, the amount of Al is limited to 0.3% or less.

[0042] In various embodiments, Nitrogen (N) is contained in an amount of 0.03% or less (excluding 0%). N may be formed into AlN or TiN through the reaction with Al or Ti, thereby exhibiting grain refinement effects and maximizing the hardenability of B due to the formation of TiN. However, when excess N is contained, the hardenability of steel may deteriorate due to the reaction with B. Hence, the amount of N is limited to 0.03% or less.

[0043] In various embodiments, Oxygen (O) is contained in an amount of 0.003% or less (excluding 0%). O is coupled with Si or Al, thus forming hard oxide-based non-metal inclusions and deteriorating fatigue life characteristics. Hence, the amount of O is as low as possible, but its presence is acceptable in an amount up to 0.003% in various embodiments of the present invention.

[0044] The remaining elements, other than the above elements, are composed of Fe and inevitable impurities.

[0045] Below, various embodiments of the present invention are described through the following examples and comparative examples.

[0046] Tests for producing spring steel in Examples and Comparative Examples were performed under the conditions of industrial production of spring steel. As shown in FIG. 1, molten steel was produced using elements in the amounts shown in FIG. 1, and the resulting wire rod was sequentially subjected to constant-temperature heat treatment, drawing, quench tempering, and dip quenching, resulting in steel wires. Specifically, the wire rod was maintained at 940 to 960° C. for 3 to 5 min, rapidly cooled to 640 to 660° C., maintained at that temperature for 2 to 4 min, and cooled to 18 to 22° C. for 0.5 to 1.5 min. Such constant-temperature heat treatment is performed to facilitate the subsequent drawing process, whereby pearlite is formed in the wire rod.

[0047] The constant-temperature heat treated wire rod is manufactured so as to have a desired wire diameter through multiple drawing processes. In various embodiments of the present invention, drawing was performed to obtain a wire rod having a wire diameter of 4 mm.

[0048] The drawn wire rod was heated again, maintained at 940 to 960° C. for 3 to 5 min, rapidly cooled to 45 to 55° C., and tempered for 0.5 to 1.5 min. Thereafter, the wire rod was subjected to dip quenching in a manner in which it was heated to 440 to 460° C., maintained at that temperature for 2 to 4 min, and rapidly cooled. Through quench tempering, martensite was formed in the wire rod, thus ensuring strength, and through dip quenching, tempered martensite was formed on the surface of the wire rod, thereby ensuring strength and toughness.

[0049] Next, the properties of the spring steel in Examples and Comparative Examples were tested.

[0050] The tensile strength, hardness, wire fatigue life, pit depth, component corrosion fatigue life, cyclic corrosion fatigue life, and proportions of cementite/carbide/boride of the spring steel in Examples and Comparative Examples were measured. The results are shown in FIG. 2.

[0051] For wire samples having a wire diameter of 4 mm, tensile strength was measured by a 20-ton tester according to KS B 0802 using a standard tensile test specimen (KS B 0801), and hardness was measured at 300 gf using a micro Vickers hardness tester according to KS B 0811.

[0052] Also, the fatigue life of wire samples having a wire diameter of 4 mm was measured via rotary bending fatigue testing (wire fatigue life testing) according to KS B ISO 1143, and L10 life was the basic rating life at 90% reliability upon one million revolutions, which corresponded to 1/7 of the mean time between failures, or L50 mean life. Corrosion fatigue was measured using salt spray testing (KS D 9502, ISO 3768/7263).

[0053] The proportions of cementite/carbide/boride were calculated through thermodynamic DB-based ThermoCalc. The criterion for the proportion of cementite was less than 9%, the criterion for the proportion of carbide was greater than 3%, and the criterion for the proportion of boride was greater than 0.01%.

[0054] As shown in FIG. 2, conventional steel did not contain Mo, Nb, Co, B and W and thus did not satisfy all the requirements of tensile strength, hardness, wire fatigue life, pit depth, component corrosion fatigue life, cyclic corrosion fatigue life, and proportions of cementite/carbide/boride according to various embodiments of the present invention.

[0055] In Comparative Examples 1 to 18, falling out of the amount ranges of alloy elements according to various embodiments of the present invention, were improved somewhat in tensile strength, hardness, wire fatigue life, pit depth, component corrosion fatigue life, cyclic corrosion fatigue life, and proportions of cementite/carbide/boride, compared to conventional steel, but did not satisfy all of the requirements of various embodiments of the present invention.

[0056] Particularly in Comparative Example 1, containing Cr in a smaller amount, hardness and wire fatigue life were maintained similar to that of conventional steel, but tensile strength, component corrosion fatigue life and cyclic corrosion fatigue life were somewhat reduced, and pit depth was further increased.

[0057] Comparative Example 2 contained an excess of Cr, Comparative Example 4 contained an excess of Mo, and Comparative Example 5 contained Ni in a smaller amount, and thus tensile strength, hardness, wire fatigue life, pit depth, component corrosion fatigue life, and proportions of cementite/carbide/boride were improved but cyclic corrosion fatigue life was decreased somewhat compared to conventional steel.

[0058] Comparative Example 3 contained Mo in a smaller amount, and thus fatigue life-related characteristics were deteriorated compared to conventional steel.

[0059] In Comparative Examples 6 to 12, where the respective amounts of Ni, V, Nb and Ti are smaller or greater, tensile strength and hardness were improved but cyclic corrosion fatigue life was decreased and pit depth was further increased compared to conventional steel.

[0060] Comparative Examples 13 and 14 contained an excess of Co, and thus wire fatigue life, pit depth, component corrosion fatigue life and cyclic corrosion fatigue life were not improved or were decreased somewhat compared to conventional steel. Although tensile strength and hardness were improved, the extent of improvement thereof did not reach the levels required of various embodiments of the present invention.

[0061] In Comparative Examples 15 to 18, where the amounts of B and W are smaller or greater, wire fatigue life, component corrosion fatigue life, cyclic corrosion fatigue life, tensile strength and hardness were improved but pit depth was further increased compared to conventional steel, and the proportions of cementite/carbide/boride were unsatisfactory.

[0062] On the other hand, the steel of Examples 1 to 3 satisfied all the requirements of various embodiments of the present invention and exhibited a tensile strength of 2200 MPa or more, a hardness of 700 HV or more, and a pit depth of 20 μ m or less. Also, the steel endured a wire fatigue life test at least 230 thousand times, a component corrosion fatigue life test at least 30 thousand times, and a cyclic corrosion fatigue life test at least 400 thousand times. The proportion of cementite was less than 9%, the proportion of carbide exceeded 3%, and the proportion of boride exceeded 0.01%.

[0063] FIG. 3 is a graph showing the results of calculation of the phase transformation at different temperatures of the spring steel according to various embodiments of the present invention, and FIG. 4 is a graph showing the results of calculation of the phase transformation at different temperatures in the cementite tissue of the spring steel according to various embodiments of the present invention.

[0064] FIG. 3 is a graph showing the results of calculation of the phase transformation at different temperatures of the steel having an alloy composition of Fe-0.6C-1.5Si-1.2Mn-1.2Cr-0.8Ni-0.5Mo-0.3V-0.3Nb-0.025Ti-0.1Co-0.002B-0.1W. When the alloy composition of the invention is provided, three kinds of metal carbides (MX, FCC#2(MC), FCC#3(MC)) and boride (MB) are formed in Ti-rich and Cr-rich solids, whereby an increase in strength and fatigue life can be expected. The “M” of MX, FCC#2(MC) and FCC#3(MC) of FIG. 3 indicates various kinds of metal elements contained in the alloy composition, and MX, FCC#2(MC) and FCC#3(MC) designate various kinds of metal carbides.

[0065] FIG. 4 is a graph showing the results of calculation of the phase transformation at different temperatures in the cementite tissue of the steel having an alloy composition of Fe-0.6C-1.5 Si-1.2Mn-1.2Cr-0.8Ni-0.5Mo-0.3V-0.3Nb-0.025Ti-0.1Co-0.002B-0.1W, from which the generation of complex behavior of 10-membered elements in the cementite may be predicted, whereby the uniform distribution of fine carbide can be expected.

[0066] For convenience in explanation and accurate definition in the appended claims, the terms “upper” or “lower”, “inner” or “outer” and etc. are used to describe features of the exemplary embodiments with reference to the positions of such features as displayed in the figures.

[0067] The foregoing descriptions of specific exemplary embodiments of the present invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teachings. The exemplary embodiments were chosen and described in order to explain certain principles of the invention and their practical application, to thereby enable others skilled in the art to make and utilize various exemplary embodiments of the present invention, as well as various alternatives and modifications thereof. It is intended that the scope of the invention be defined by the Claims appended hereto and their equivalents.

What is claimed is:

1. A high-strength spring steel having excellent corrosion resistance, suitable for use as steel for a coil spring of a vehicle suspension, the high-strength spring steel comprising: 0.4 to 0.9 wt % of Carbon (C), 0.9 to 2.3 wt % of Silicon (Si), 0.5 to 1.2 wt % of Manganese (Mn), 0.6 to 1.5 wt % of Chromium (Cr), 0.01 to 0.5 wt % of Molybdenum (Mo), 0.01 to 0.9 wt % of Nickel (Ni), 0.5 wt % or less (excluding 0 wt %) of Vanadium (V), 0.5 wt % or less (excluding 0 wt %) of Niobium (Nb), 0.3 wt % or less (excluding 0 wt %) of Titanium (Ti), 1.0 wt % or less (excluding 0 wt %) of Cobalt (Co), 0.1 wt % or less (excluding 0 wt %) of Boron (B), 0.3 wt % or less (excluding 0 wt %) of Tungsten (W), 0.3 wt % or less (excluding 0 wt %) of Copper (Cu), 0.3 wt % or less (excluding 0 wt %) of Aluminum (Al), 0.03 wt % or less (excluding 0 wt %) of Nitrogen (N), 0.003 wt % or less (excluding 0 wt %) of Oxygen (O), and a remainder of Iron (Fe) and inevitable impurities.

2. The high-strength spring steel of claim 1, wherein the spring steel has a tensile strength of 2200 MPa or more.

3. The high-strength spring steel of claim 1, wherein the spring steel has a hardness of 700 HV or more.

4. The high-strength spring steel of claim 1, wherein the spring steel has a pit depth of 20 μ m or less.

5. The high-strength spring steel of claim 1, wherein the spring steel endures a bending fatigue test at least 320 thousand times.

6. The high-strength spring steel of claim 1, wherein the spring steel endures a component corrosion fatigue life test at least 30 thousand times.

7. The high-strength spring steel of claim 1, wherein the spring steel endures a cyclic corrosion fatigue life test at least 400 thousand times.

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