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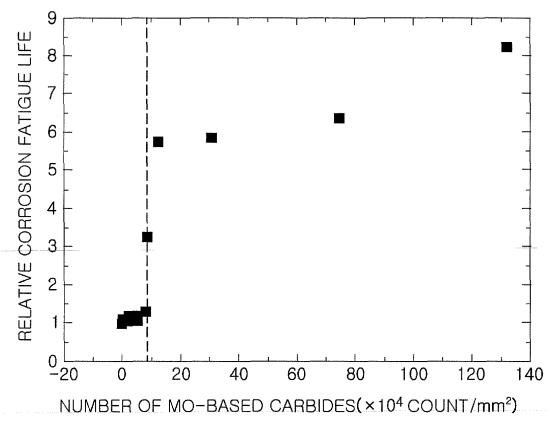
(54) WIRE ROD FOR SPRINGS WITH EXCELLENT CORROSION FATIGUE RESISTANCE, STEEL WIRE, AND MANUFACTURING METHOD THEREOF

(57) One aspect of the present invention relates to a wire rod for springs with high strength and excellent corrosion fatigue resistance, in which a combination of Cr, Cu, and Ni content is controlled to an appropriate level, the maximum depth of corrosion pits is set to be below a certain level, and fine carbides containing Mo are set to be at a certain level or greater.

[FIG. 2]



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Description

[Technical Field]

[0001] The present disclosure relates to a wire rod for springs with high strength and excellent corrosion fatigue resistance, a steel wire, and a method of manufacturing the same, which may preferably be applied to a suspension spring, a torsion bar, and a stabilizer, or the like, used for vehicles.

[Background Art]

[0002] Recently, it has been required to reduce weights of materials used for vehicles to improve fuel efficiency of vehicles, and a suspension spring has been designed to be manufactured using a high strength material having strength of 1800 MPa or higher after a quenching and tempering process so as to respond to the demand for lightweight materials.

[0003] Steel used for springs is formed as a spring through the following processes. After manufacturing a wire rod through a hot rolling process, in case of a hot formed spring, the wire rod is manufactured as a spring through a heating process, a forming process, and a quenching and tempering process performed in order, and in case of a cold formed spring, the wire rod is manufactured as a spring through a drawing process and a quenching and tempering process performed in order.

[0004] Generally, when a material is designed to have high strength, toughness may be degraded due to grain boundary embrittlement resistance, or for other reasons, and also, crack sensitivity may increase. Thus, although high strength may be achieved, if corrosion resistance of a material degrades, an externally exposed component, such as a suspension spring of a vehicle, may have a corrosion pit created in a region in which paint is removed, and the component may be damaged at an early stage due to fatigue cracks spreading from the corrosion pit.

[0005] A corrosion environment of a suspension spring may be increased due to snow melting agents used to prevent a road surface from freezing in winter. Accordingly, demand for steel for springs with high strength and improved corrosion fatigue resistance has increased.

[0006] Corrosion fatigue of a suspension spring refers to breakage of a spring. When paint on the surface of a spring is removed due to pebbles on a road surface or foreign objects, a material of the portion with no paint is exposed externally, which may cause a pitting corrosion reaction, and a corrosion pit may be created and grown, such that cracks may be generated and spread from the pit. Then, hydrogen from an external source may be concentrated on the cracks and may cause hydrogen embrittlement, which may lead to spring breakage.

[0007] To improve corrosion fatigue resistance of a spring, the method of increasing types and amounts of contents of alloy elements have been used in the prior art. In reference 1, a content of Ni is increased to 0.55 weight% to improve corrosion resistance, thereby increasing corrosion fatigue life, and in reference 2, a content of Si is increased to create micronized carbide precipitated during tempering, thereby improving strength against corrosion fatigue. In reference 3, Ti precipitation, a strong hydrogen trapping site, and a V, Nb, Zr, and Hf precipitation, weak hydrogen trapping sites, are balanced to improve hydrogen delayed fracture resistance, thereby improving a corrosion fatigue life of a spring.

[0008] However, as Ni is an expensive element, material costs may increase when a large amount of Ni is added. As for Si, Si is a representative element causing decarburization, and thus, if a content of Si is increased, it may cause substantial risk. Ti, V, Nb, and the like, elements creating precipitation, may degrade the corrosion fatigue life because the elements may crystallize coarse carbonitrides from liquid materials when the materials are solidified.

[0009] To achieve high strength of a spring, the method of adding alloy elements and the method of decreasing a tempering temperature have been used in the prior art. As the method of achieving high strength by adding alloy elements, the method of increasing quenching hardness using C, Si, Mn, and Cr has been used, and strength of a steel material may increase through a rapid cooling and a tempering heat treatment using Mo, Ni, V, Ti, and Nb, and the like, relatively expensive alloy elements. The techniques, however, may increase material costs.

[0010] Strength of a steel material has also been increased by changing heat treatment conditions in a general component system without changing an alloy composition. When a tempering temperature is deceased, strength of a material may increase. However, when a tempering temperature decreases, an area reduction rate may decrease, which may cause degradations in toughness, and may also cause early breakage of a spring while a spring is formed and used, and other problems .

[0011] Thus, it has been necessary to develop a wire rod for springs with high strength and excellent corrosion fatigue resistance, a steel wire, and a method of manufacturing the same.

(Prior Art)

[0012]

(Reference 1) Japanese Laid-Open Patent Publication No. 2008-190042
(Reference 2) Japanese Laid-Open Patent Publication No. 2011-074431
(Reference 3) Japanese Laid-Open Patent Publication No. 2005-023404

[Disclosure]

[Technical Problem]

[0013] An aspect of the present disclosure is to provide a wire rod for springs with high strength and excellent corrosion fatigue resistance, a steel wire, and a method of manufacturing the same by controlling a combination of contents of Cr, Cu, and Ni to a certain level, controlling a maximum depth of a corrosion pit to a certain level or less, and controlling a content of fine carbide containing Mo to a certain level or higher.

[0014] Meanwhile, the purposes of the present disclosure are not limited to the features described above. The purposes of the present disclosure may be understood on the basis of the descriptions in the specification, and it may not be difficult for a person having skilled in the art in the field in which the present disclosure is included to understand additional purposes of the present disclosure.

[Technical Solution]

[0015] An aspect of the present disclosure relates to a wire rod for springs with excellent corrosion fatigue resistance including C: 0.40 to 0.70%, Si: 1.30 to 2.30%, Mn: 0.20 to 0.80%, Cr: 0.20 to 0.80%, Cu: 0.01 to 0.40%, Ni: 0.10 to 0.60%, Mo: 0.01 to 0.40%, P: 0.02% or less, S: 0.015% or less, N: 0.01% or less, and a balance of Fe and inevitable impurities by weight%, the wire rod satisfies equation 1 below,

$$\text{equation 1: } -0.14 \leq 0.70[Cr] - 0.76[Cu] - 0.24[Ni] \leq 0.47,$$

where each element symbol is a value of a content of each element measured by weight%, a microstructure comprises 50 area% or less of ferrite and a balance of pearlite, and the wire rod comprises 8.0×10^4 count/mm^2 or higher of Mo-based carbides.

[0016] Another aspect of the present disclosure relates to a method of manufacturing a wire rod for springs with excellent corrosion fatigue resistance including heating a billet to 900 to 1100°C, the billet comprising C: 0.40 to 0.70%, Si: 1.30 to 2.30%, Mn: 0.20 to 0.80%, Cr: 0.20 to 0.80%, Cu: 0.01 to 0.40%, Ni: 0.10 to 0.60%, Mo: 0.01 to 0.40%, P: 0.02% or less, S: 0.015% or less, N: 0.01% or less, and a balance of Fe and inevitable impurities by weight% and satisfying equation 1 below, equation 1: $-0.14 \leq 0.70[Cr] - 0.76[Cu] - 0.24[Ni] \leq 0.47$, where each element symbol is a value of a content of each element measured by weight%, obtaining a wire rod by finishing-hot-rolling the heated billet at 800 to 1000°C, and coiling the wire rod and cooling the wire rod such that the time for maintaining the wire rod at a temperature in a range of 600 to 700°C is 31 seconds or longer.

[0017] Another aspect of the present disclosure relates to a steel wire for springs with excellent corrosion fatigue resistance and a method of manufacturing the same.

[0018] The solutions described above do not necessarily list all of the features of the present disclosure. Various features of the present disclosure, and advantages and effects thereof will further be understood with reference to exemplary embodiments described below.

[Advantageous Effects]

[0019] According to the present disclosure, a wire rod for springs with high strength and excellent corrosion fatigue resistance, a steel wire, and a method of manufacturing the same may be provided.

[Description of Drawings]

[0020]

FIG. 1 is a graph illustrating a relative corrosion fatigue life depending on a maximum depth of a corrosion pit according to an example embodiment; and
FIG. 2 is a graph illustrating a relative corrosion fatigue life depending on the number of Mo-based carbides according to an example embodiment.

[Best Mode for Invention]

[0021] Hereinafter, embodiments of the present disclosure will be described with reference to the accompanied drawings. The present disclosure, however, may be modified to various other embodiments, and the scope of the present disclosure may not be limited to exemplary embodiments described below. These embodiments are provided to help those skilled in the art to understand the present disclosure.

[0022] To address the issues described above, in the present disclosure, various effective factors affecting corrosion resistance of steel for springs have been examined. Also, corrosion fatigue is the breakage of a spring. When a corrosion pit is created as paint on a surface of a spring is removed, cracks are generated and spread from the corrosion pit, and hydrogen from outside is concentrated on the cracks such that a spring may be broken. The present disclosure is suggested upon the grounds as below in consideration of the issue described above.

[0023] Cr, one of alloy elements, is generally known as an element which may improve corrosion resistance, but as a result of a salt water spraying test, corrosion fatigue resistance was degraded when a content of Cr increased. Also, Cu and Ni made corrosion rust formed on a surface of a material amorphous during a corrosion reaction such that a corrosion speed decreased. Thus, to improve corrosion fatigue resistance of steel for springs, it may be important to control combination of contents of Cr, Cu, and Ni to an appropriate level.

[0024] Also, the greater the maximum depth of a corrosion pit generated on a surface of a material in the corrosion reaction, the further the corrosion fatigue resistance was degraded. Particularly, the narrower and deeper the width of a corrosion pit, the further the corrosion fatigue resistance may degrade. Thus, to improve corrosion fatigue resistance properties of steel for springs, it may be necessary to control a maximum depth of a corrosion pit to a certain level or less.

[0025] In addition, to prevent hydrogen from outside from being concentrated on cracks, it may be necessary to trap hydrogen using fine carbides, and carbides including alloy elements of V, Ti, Nb, Mo, and the like, as main ingredients, not cementite, may be used as the fine carbide. Also, nano-sized and fine Mo-based carbides precipitated at 700°C or less may effectively trap hydrogen, and when carbides include V, Ti, Nb, and other like, besides Mo, as main ingredients, the carbides may have an excellent hydrogen trapping effect when Mo is contained.

[0026] Thus, in the present disclosure, a wire rod for springs with high strength and excellent corrosion fatigue resistance, a steel wire, and a method of manufacturing the same may be provided by controlling combination of contents of Cr, Cu, and Ni, controlling a maximum depth of a corrosion pit to a certain level or less, and controlling a content of fine carbide including Mo to a certain level or higher.

Wire Rod for Springs with Corrosion Fatigue Resistance

[0027] In the description below, a wire rod for springs with excellent corrosion fatigue resistance will be described in greater detail.

[0028] A wire rod for springs with excellent corrosion fatigue may include C: 0.40 to 0.70%, Si: 1.30 to 2.30%, Mn: 0.20 to 0.80%, Cr: 0.20 to 0.80%, Cu: 0.01 to 0.40%, Ni: 0.10 to 0.60%, Mo: 0.01 to 0.40%, P: 0.02% or less, S: 0.015% or less, N: 0.01% or less, and a balance of Fe and inevitable impurities by weight%, the wire rod may satisfies equation 1, a microstructure may include 50 area% or less of ferrite and a balance of pearlite, and the wire rod may include 8.0×10^4 count/mm^2 or higher of Mo-based carbides.

[0029] In the description below, an alloy composition of the example embodiment will be described in greater detail. In example embodiments, a unit of each element content may be weight% unless otherwise indicated. Also, the alloy composition may be applied to the method of manufacturing a wire rod, and may also be applied to a steel wire and the method of manufacturing the steel wire.

C: 0.40 to 0.70%

[0030] C is an essential element added to secure strength of a spring. To draw the effect of C, it may be preferable to add 0.40% or higher of C. When a content of C exceeds 0.70%, a twin-type martensite structure may be formed during a heat treatment in a quenching and tempering process, and cracks may be created in a material, which may significantly decrease fatigue life, may increase defect sensitivity, and may significantly degrade fatigue life or fracture stress when a corrosion pit is created. Thus, a preferable content of C may be 0.40 to 0.70%.

[0031] A more preferable lower limit content of C may be 0.45%, and a more preferable upper limit content may be 0.65%.

Si: 1.30 to 2.30%

[0032] Si may be dissolved in ferrite, may enhance strength of a base material and may improve deformation resistance.

[0033] When a content of Si is less than 1.30%, the effect of Si dissolved in ferrite to enhance strength of a base

material and to improve deformation resistance may be insufficient. Thus, a preferable lower limit content of Si may be 1.30%, and a more preferable lower limit may be 1.45%. When a content of Si exceeds 2.30%, the effect of improvement in deformation resistance may be saturated such that no significant effect may be obtained from additionally added Si, and surface decarburization may occur during a heat treatment. Thus, a preferable upper limit content of Si may be 2.30%, and a more preferable upper limit may be 2.25%.

Mn: 0.20 to 0.80%

[0034] If Mn is included in the steel material, Mn may secure strength of a steel material by improving hardenability of the steel material.

[0035] When a content of Mn is less than 0.20%, it may be difficult to obtain sufficient strength and hardenability required for a material for springs with high strength, whereas, when a content of Mn exceeds 0.80%, hardenability may increase excessively such that a martensite hard structure may easily be creased during cooling after a hot rolling process, and MnS inclusions may increasingly be created, which may degrade corrosion fatigue resistance properties. Thus, a preferable content of Mn may be 0.20 to 0.80%

[0036] A more preferable lower limit content of Mn may be 0.30%, and an even more preferable lower limit content may be 0.40%. A more preferable upper limit content of Mn may be 0.75%, and an even more preferable upper limit content may be 0.70%.

Cr: 0.20 to 0.80%

[0037] Cr may be used to prevent oxidation resistance, temper softening properties, and surface decarburization and to secure hardenability.

[0038] When a content of Cr is less than 0.20%, it may be difficult to secure the sufficient effect of oxidation resistance, temper softening properties, surface decarburization, and hardenability. When a content of Cr exceeds 0.80%, deformation resistance may degrade such that strength may degrade. Thus, a preferable content of Cr may be 0.20 to 0.80%.

[0039] A more preferable lower limit content of Cr may be 0.22%, and an even more preferable upper limit may be 0.75%.

Cu: 0.01 to 0.40%

[0040] Cu may be added to improve corrosion resistance. When a content of Cu is less than 0.01%, the effect of improvement in corrosion resistance may be insufficient, whereas, when a content of Cu exceed 0.40%, embrittlement may degrade during a hot rolling process, which may cause cracks, and other problems . Thus, a preferable content of Cu may be 0.01 to 0.40%. A more preferable content of Cu may be 0.05 to 0.30%.

Ni: 0.10 to 0.60%

[0041] Ni may be added to improve hardenability and toughness . When a content of Ni is less than 0.10%, the effect of hardenability and toughness may not be sufficient, whereas, when a content of Ni exceeds 0.60%, the amount of residual austenite may increase, which may decrease fatigue life, and may increase manufacturing costs as Ni is expensive. Thus, a preferable content of Ni may be 0.10 to 0.60%.

Mo: 0.01~0.40%

[0042] Mo may contribute to refining microstructure by forming carbonitride together with carbon or nitrogen, and may work as a trap site for hydrogen. To obtain the effect, a preferable content of Mo may be 0.01% or higher. However, when a content of Mo is excessive, it may be highly likely than a martensite hard structure may be created during cooling after a hot rolling process, and coarse carbonitride may be created, which may degrade flexibility of a steel material. Thus, a preferable upper limit content of Mo may be 0.40%.

P: 0.02% or less

[0043] P is impurities. P may be segregated into a grain boundary and may degrade toughness. Thus, it may be preferable to control an upper limit content of P to be 0.02%.

S: 0.015% or less

[0044] S is impurities. S may be segregated into a grain boundary as an element having a low melting point and may

degrade toughness, and may also create large amount of MnS, which may degrade corrosion resistance properties of a spring. Thus, it may be preferable to control an upper limit content of S to be 0.015%.

N: 0.01% or less

[0045] Nitride (N) may easily create BN by reacting with boron (B), and may decrease a quenching effect, and thus, a content of N may need to be controlled to be relatively low. Considering process load, it may be preferable to control a content of N to be 0.01% or less.

[0046] Iron (Fe) may also be added in the example embodiment. In a general manufacturing process, unintended impurities from raw materials or a surrounding environment may inevitably be added, and thus, Fe may not be excluded. A person skilled in the art may be aware of such impurities, and thus, the impurities may not be described in detail in the example embodiment.

$$\text{Equation 1: } -0.14 \leq 0.70[Cr] - 0.76[Cu] - 0.24[Ni] \leq 0.47$$

(In equation 1, each element symbol is a value of a content of each element measured by weight%)

[0047] Cr, Cu, and Ni may need to satisfy each element content described above, and may also satisfy equation 1 above.

[0048] Cr is known as an element which may improve corrosion resistance, but as a content of Cr increases in steel for springs, corrosion fatigue resistance may degrade. The reason is that Cr may decrease pH of a pit bottom during a corrosion reaction such that Cr may create a strongly acid atmosphere in the pit and may increase a maximum depth of the pit. Thus, the higher the content of Cr, the more the corrosion fatigue resistance may degrade.

[0049] Cu and Ni may make corrosion rust formed on a surface of a material amorphous in a corrosion reaction such that Cu and Ni may decrease a corrosion speed. Thus, the correlation between contents of Cr, Cu, and Ni and the decrease of corrosion fatigue resistance of steel for springs was examined, and the effect rate of Cr was 0.70, the effect rate of Cu was -0.76, and the effect rate of Ni was -0.24. By controlling the correlation to satisfy equation 1 above, corrosion fatigue resistance was improved.

[0050] In addition to the alloy composition described above, one or more elements selected from among V: 0.01 to 0.20%, Ti: 0.01 to 0.15%, and Nb: 0.01 to 0.10% may further be added.

V: 0.01 to 0.20%

[0051] V may improve strength and may contribute to grain refinement. Further, V may work as a trap site for hydrogen infiltrating steel by forming carbonitride together with carbon (c) or nitrogen (N) and such that V may prevent hydrogen infiltration in steel and may decrease corrosion of steel.

[0052] When a content of V is less than 0.01%, the above-described effect may not be sufficient. When a content of V is excessive, manufacturing costs may increase. Thus, a preferable upper limit content of V may be 0.20%.

Ti: 0.01 to 0.15%

[0053] Ti may improve spring properties by causing a precipitation hardening effect by forming carbonitride, and may improve strength and toughness by refining grains and reinforcing precipitation. Ti may also work as a trap site for hydrogen infiltrating steel such that Ti may prevent hydrogen infiltration in steel and may decrease corrosion of steel.

[0054] When a content of Ti is less that 0.01 %, it may not be effective in that a frequency of precipitations reinforcing precipitation and working as a hydrogen trap site decreases. When a content of Ti exceeds 0.15%, manufacturing costs may significantly increase, the effect of improvement in spring properties due to precipitations may be saturated, and the amount of coarse alloy carbide which has not been dissolved into a base material during a heat treatment of austenite such that the coarse alloy carbide may work as a non-metal inclusion. Accordingly, the effect of fatigue properties and precipitation reinforcement may degrade.

Nb: 0.01 to 0.10%

[0055] Nb may contribute to structure refinement by forming carbonitride together with carbon or nitrogen, and may work as a trap site for hydrogen. To obtain the effect, a preferable content of Nb may be 0.01% or higher. However, when a content of Nb is excessive, coarse carbonitride may be formed, which may degrade ductility of steel. Thus, a preferable upper limit content of Nb may be 0.10%.

[0056] A microstructure of a wire rod in the example embodiment may include 50 area% or less of ferrite, and a balance of pearlite. The area fraction above was measured exclusive of precipitation.

[0057] When an area fraction of ferrite exceeds 50 area%, strength of a material may significantly decrease such that, after a final heat treatment, a desirable level of strength may not be implemented.

[0058] Also, the remainder excluding ferrite is pearlite. When hard structure such as martensite is existed in addition to ferrite and pearlite, a wire rod may be broken in a process of drawing the wire rod.

[0059] The wire rod in the example embodiment may include 8.0×10^4 count/mm^2 or higher of Mo-based carbides.

[0060] To prevent hydrogen from outside from being concentrated on cracks, hydrogen may need to be trapped using fine carbide, and carbide including alloy elements of V, Ti, Nb, Mo, or the like, as main ingredients, not cementite, may be used as the fine carbide. The carbide including Mo as a main ingredient may be precipitated in nano-size within a temperature in a range of 600 to 700°C such that a hydrogen trapping effect may significantly increase. When the carbides include V, Ti, Nb, and the like, as main ingredients, a hydrogen trapping effect may significantly increase when Mo is contained.

[0061] Thus, it may be preferable to include 8.0×10^4 count/mm^2 or higher of Mo-based carbides, and more preferably, 8.5×10^4 count/mm^2 or higher of Mo-based carbides may be included.

[0062] The number of Mo-based carbides may not be significantly changed when a steel wire is manufactured, but the number of Mo-based carbides may decrease slightly. Thus, it may be more preferable to secure 9.0×10^4 count/mm^2 or higher of Mo-based carbides in a wire rod state.

[0063] The Mo-based carbides may include 5 weight% or higher of Mo based on carbides. That is because, as described above, when the carbides include V, Ti, Nb, and the like, as main ingredients, a hydrogen trapping effect may significantly increase when Mo is contained.

Method of Manufacturing Wire Rod for Springs with Excellent Corrosion Fatigue Resistance

[0064] In the description below, a method of manufacturing a wire rod for springs with excellent corrosion fatigue resistance will be described in greater detail in accordance with an example embodiment.

[0065] The method of manufacturing a wire rod for springs with excellent corrosion fatigue resistance may include heating a billet satisfying the above-described alloy composition to 900 to 1100°C, obtaining a wire rod by finishing-hot-rolling the heated billet at 800 to 1000°C, and coiling the wire rod and cooling the wire rod such that the time for maintaining the billet at a temperature in a range of 600 to 700°C may be 31 seconds or longer.

Heating Billet

[0066] The billet satisfying the above-described alloy composition may be heated to 900 to 1100°C.

[0067] The heating temperature of the billet may be 900°C or higher because, by melting all coarse carbides generated during a molding process, the alloy elements may be uniformly distributed in austenite. When a heating temperature of the billet exceeds 1100°C, the billet may be excessively heated such that heat consumption may increase, and the time may be prolonged, which may cause excessive decarburization.

Hot-Rolling

[0068] A wire rod may be obtained by finishing-hot-rolling the heated billet to 800 to 1000°C.

[0069] The temperature of the finishing-rolling may be 800°C or higher to facilitate precipitation of fine carbides. When the temperature of the finishing-rolling is less than 800°C, load taken in a roller may increase, and when the temperature of the finishing-rolling exceeds 1000°C, a size of a grain may increase such that toughness may degrade, and transformation may be delayed in a cooling process, and accordingly, martensite hard structure may be created.

Coiling and Cooling

[0070] After the wire rod is coiled, the wire rod may be cooled such that the time for maintaining the wire rod at a temperature in a range of 600 to 700°C may be 31 seconds or longer.

[0071] The reason for controlling the time for maintaining the wire rod at a temperature in a range of 600 to 700°C to be 31 seconds or longer may be to secure sufficient time for completing pearlite transformation without creating martensite hard structure during a cooling process, and to sufficiently precipitate fine carbides including Mo as a main ingredient.

Steel Wire for Springs with Excellent Corrosion Fatigue Resistance

[0072] A steel wire for springs with excellent corrosion fatigue resistance in an example embodiment may satisfy the

above-described alloy composition, a microstructure may be a tempered martensite single phase, and the steel wire may include 8.0×10^4 count/mm^2 or higher of Mo-based carbides. As a microstructure is a tempered martensite single phase, and 8.0×10^4 count/mm^2 or higher of Mo-based carbides are included, corrosion fatigue resistance may improve. The tempered martensite single phase may refer to a structure mostly formed of tempered martensite with a balance of an inevitable impure structure.

[0073] To prevent hydrogen from outside from being concentrated on cracks, hydrogen may need to be trapped using fine carbides, and carbides including alloy elements of V, Ti, Nb, Mo, or the like, as main ingredients, not cementite, may be used as the fine carbides. The carbides including Mo as a main ingredient may be precipitated in nano-size within a temperature in a range of 600 to 700°C such that a hydrogen trapping effect may significantly increase, and when carbides include V, Ti, Nb, or the like, as main ingredients, a hydrogen trapping effect may significantly increase when Mo is contained. Thus, it may be preferable to include 8. 0×10^4 count/mm^2 or higher of Mo-based carbides, and more preferably, 8.5×10^4 count/mm^2 or higher of Mo-based carbides may be included. The Mo-based carbides may be created when a wire rod is manufactured, and the Mo-based carbides may not be changed but may slightly decrease during a heating process and a cooling process when a steel wire is manufactured.

[0074] A maximum depth of a corrosion pit of the steel wire in the example embodiment may be 120 μm or less.

[0075] In a corrosion reaction, the deeper the maximum depth of a corrosion pit created on a surface of a material, the more the corrosion fatigue resistance properties of steel for springs may degrade. Particularly, the narrower and deeper the corrosion pit, the greater the stress applied to the pit, which may significantly degrade corrosion fatigue resistance.

[0076] The maximum depth of the corrosion pit may be measured after 14 repetitions of a cycle in which a sample of the steel wire was put in a salt water spray tester, 5% salt water was sprayed onto the steel wire sample for 4 hours in an atmosphere at 35°C, the steel wire sample was dried for 4 hours at atmosphere at a temperature of 25°C and humidity of 50%, and the steel wire sample was wet for 16 hours until humidity became 100%. The harshest condition was set in consideration of usage environment of steel for springs, and when a maximum depth of the corrosion pit is 120 μm or less under the above-described conditions, improved corrosion fatigue resistance could be secured.

[0077] The tensile strength of steel wire in the example embodiment may be 1800MPa or higher.

Method of Manufacturing Steel Wire for Springs with Excellent Corrosion Fatigue Resistance

[0078] A method of manufacturing a steel wire for springs with excellent corrosion fatigue resistance in an example embodiment may include obtaining a steel wire by drawing the wire rod manufactured by the method of manufacturing a wire rod described in the aforementioned example embodiment, austenitizing the steel wire by heating the steel wire to 850~1000°C and maintaining the heated steel wire for 1 minute or longer, and oil-cooling the austenitized wire rod to 25 to 80°C and tempering the wire rod at 350 to 500°C.

[0079] When the maintaining time after heating is less than 1 minute, structures of ferrite and pearlite may not be sufficiently heated such that the wire rod may not be transferred to be austenite, and thus, it may be preferable to control the heating time to be 1 minute or longer. Also, the oil-cooling temperature is generally used condition, and thus, the oil-cooling temperature may not be particularly limited.

[0080] When the tempering temperature is less than 350°C, toughness may not be secured, and accordingly, the wire rod may be broken during a forming process and in a product state. When the tempering temperature exceeds 500°C, strength may degrade. Thus, a preferable tempering temperature may be 350 to 500°C.

[Mode for Invention]

[0081] In the description below, embodiments of the present disclosure will be described in greater detail. It should be noted that the exemplary embodiments are provided to describe the present disclosure in greater detail, and to not limit the scope of rights of the present disclosure. The scope of rights of the present disclosure may be determined on the basis of the subject matters recited in the claims and the matters reasonably inferred from the subject matters.

[0082] A billet having a composition as in Table 1 below was heated to 1000°C, and was coiled after finishing-rolling at 900°C. In a cooling process after coiling, a temperature in a range of 600 to 700°C was maintained for maintaining times listed in Table 2 below, and a wire rod was manufactured. A microstructure of the wire rod was observed and listed in Table 2 below.

[0083] The wire rod was drawn, was heated at 975°C for 15 minutes, was put in oil of 70°C and was rapidly cooled, and the cooled wire rod was maintained at 390°C for 30 minutes, and a steel wire was manufactured.

[0084] Tensile strength of the steel wire, a maximum depth of a corrosion pit, a Mo-based carbide, and relative corrosion fatigue life were measured and listed in Table 2 below. All microstructures were martensite single phases.

[0085] The tensile strength was measured by, after gathering tensile samples of the steel wire in accordance with ASTM E 8 standard, performing a tensile test.

[0086] As for the Mo-based carbide, the sample was cut cross-sectionally, fine carbides were extracted by a replica method, and the fine carbides were analyzed using a transmission electron microscope and energy dispersive X-ray spectroscopy, and the number of carbides including 5% or higher of Mo from the result was listed in Table 1 below.

[0087] A cycle in which a sample of the steel wire was put in a salt water spray tester, 5% salt water was sprayed onto the steel wire sample for 4 hours at atmosphere of 35°C, the steel wire sample was dried for 4 hours at atmosphere of temperature of 25°C and humidity of 50%, and the steel wire sample was wet for 16 hours until humidity became 100% was repeated 14 times, and a maximum depth of a corrosion pit and a relative corrosion fatigue life were measured.

[0088] A maximum depth of a corrosion pit was measured using a confocal laser microscope.

[0089] The relative corrosion fatigue life was measured by performing a rotary bending fatigue test, a speed of the fatigue test was 3, 000 rpm, and a weight applied to the sample was 40% of tensile strength. 10 samples were tested for corrosion fatigue life, and fatigue lives of 8 samples excluding the sample having the highest fatigue life and the sample having the lowest fatigue life were averaged. The average value was determined as a corrosion fatigue life of the respective sample. Relative corrosion fatigue lives of the other samples of when a corrosion fatigue life of a comparative example 1 was 1 were listed in Table 2.

[Table 1]

Steel Type	Alloy Composition (Weight%)												Equation 1
	C	Si	Mn	Cr	Cu	Ni	Mo	P	S	N	V	Ti	Nb	
Comparative Steel 1	0.53	1.53	0.68	0.73	-	-	-	0.016	0.008	0.0049				0.51
Comparative Steel 2	0.50	1.49	0.51	0.11	0.22	0.25	-	0.009	0.005	0.0052	0.11			-0.15
Comparative Steel 3	0.63	1.62	0.40	0.26	0.28	0.62	0.16	0.010	0.010	0.0042		0.02		-0.18
Comparative Steel 4	0.55	1.85	0.61	0.86	0.10	0.19	0.14	0.011	0.007	0.0051	0.10		0.03	0.48
Comparative Steel 5	0.48	2.26	0.59	0.28	0.34	0.58	0.22	0.008	0.007	0.0046	0.08	0.03		-0.20
Inventive Steel 1	0.52	1.51	0.68	0.72	0.14	0.21	0.03	0.012	0.008	0.0045				0.35
Inventive Steel 2	0.49	1.45	0.48	0.23	0.22	0.52	0.13	0.008	0.006	0.0057				-0.13
Inventive Steel 3	0.60	1.52	0.43	0.28	0.15	0.56	0.16	0.010	0.004	0.0044	0.18		0.02	-0.05
Inventive Steel 4	0.53	1.68	0.41	0.33	0.21	0.25	0.36	0.013	0.006	0.0054		0.14		0.01
Inventive Steel 5	0.49	2.17	0.64	0.71	0.06	0.10	0.25	0.009	0.007	0.0047	0.12		0.05	0.43

[0090] In Table 1 above, equation 1 indicates values of 0.70[Cr] - 0.76[Cu] - 0.24[Ni].

[Table 2]

Classification	Steel Type	Wire Rod Microstructure (Area%)	Maintaining Time at 600 to 700℃	Steel Wire Tensile Strength (MPa)	Maximum Depth of Corrosion Pit (μm)	Mo-based Carbides ($\times 10^4$ count/mm^2)	Relative Corrosion Fatigue Life
Comparative Example 1	Comparative Steel 1	F: 24, P: 76	18	1,852	241	0	1.00
Comparative Example 2	Comparative Steel 2	F: 36, P: 64	23	1,914	187	0	1.07
Comparative Example 3	Comparative Steel 3	F: 19, P: 49, M: 10	27	2,075	145	2.18	1.16
Comparative Example 4	Comparative Steel 4	F: 17, P: 54, M: 12	29	2,038	238	5.45	1.04
Comparative Example 5	Comparative Steel 5	F: 2, P: 53, M: 19	30	1,986	132	7.96	1.28
Inventive Example 1	Inventive Steel 1	F: 14, P: 86	32	1,872	117	8.55	3.23
Inventive Example 2	Inventive Steel 2	F: 34, P: 66	46	1,883	63	12.37	5.74
Inventive Example 3	Inventive Steel 3	F: 4, P: 96	92	2,051	78	74.36	6.37
Inventive Example 4	Inventive Steel 4	F: 25, P: 75	68	2,064	103	30.54	5.86

Inventive Example 5	Inventive Steel 5	F: 37, P: 63	115	2,008	112	132.05	8.21
Comparative Example 6	Comparative Steel 1	F: 32, P: 68	76	1,866	128	0	0.97
Comparative Example 7	Comparative Steel 2	F: 31, P: 69	51	1,920	141	0	1.02
Comparative Example 8	Inventive Steel 1	F: 6, P: 85, M: 9	30	1,904	176	2.04	1.01
Comparative Example 9	Inventive Steel 2	F: 8, P: 76, M: 16	28	1,923	214	4.75	1.16

[0091] In Table 2 above, F refers to ferrite, P refers to pearlite, and M refers to martensite.

[0092] Inventive Examples 1 to 5 which satisfied the alloy composition and manufacturing conditions described in the present disclosure had excellent tensile strength and relative corrosion fatigue life. Relative corrosion fatigue lives of the comparative examples were between 0.97 and 1.28, but relative corrosion fatigue lives of the Inventive Examples were between 3.23 and 8.21, which were significantly increased.

[0093] The comparative examples secured 1800MPa or higher of tensile strength, but did not satisfy the alloy composition and manufacturing conditions described in the present disclosure, and accordingly, relative corrosion fatigue lives were deteriorated.

[0094] Maximum depths of corrosion pits of the comparative examples were 128 μm or greater, and the numbers of Mo-based carbides turned out to be less than 8×10^4 count/mm^2.

[0095] As in comparative examples 6 and 7, if the alloy composition described in the example embodiment was not satisfied, even when the manufacturing conditions described in the example embodiment were satisfied, relative corrosion fatigue lives were relatively low. Also, as in comparative examples 8 and 9, even when the alloy composition described in the example embodiment was satisfied, but when the maintaining time at 600 to 700°C was not satisfied, relative corrosion fatigue lives were relatively low.

[0096] Also, when a martensite hard structure was formed in a wire rod state as in comparative examples 3 to 5, 8, and 9, breakage of the wire rod frequently occurred during a drawing process, and accordingly, it was difficult to manufacture the wire rod as a steel wire.

[0097] FIG. 1 is a graph illustrating a relative corrosion fatigue life depending on a maximum depth of a corrosion pit according to an example embodiment. The smaller the maximum depth of a corrosion pit, the greater the relative corrosion fatigue life, and when a maximum depth of a corrosion pit is greater than 120 μm, relative corrosion fatigue life was significantly degraded.

[0098] FIG. 2 is a graph illustrating a relative corrosion fatigue life depending on the number of the Mo-based carbides. The higher the number of Mo-based carbides, the greater the relative corrosion fatigue life was increased, and when the number of the Mo-based carbides was smaller than 8.0×10^4 count/mm^2, relative corrosion fatigue life significantly was degraded.

[0099] While exemplary embodiments have been shown and described above, the scope of the present disclosure is not limited thereto, and it will be apparent to those skilled in the art that modifications and variations could be made without departing from the scope of the present invention as defined by the appended claims.

Claims

1. A wire rod for springs with excellent corrosion fatigue resistance, comprising:

C: 0.40 to 0.70%, Si: 1.30 to 2.30%, Mn: 0.20 to 0.80%, Cr: 0.20 to 0.80%, Cu: 0.01 to 0.40%, Ni: 0.10 to 0.60%, Mo: 0.01 to 0.40%, P: 0.02% or less, S: 0.015% or less, N: 0.01% or less, and a balance of Fe and inevitable

impurities by weight%,
wherein the wire rod satisfies equation 1 below:

$$\text{Equation 1: } -0.14 \leq 0.70[Cr] - 0.76[Cu] - 0.24[Ni] \leq 0.47$$

where each element symbol is a value of a content of each element measured by weight%,
wherein a microstructure comprises 50 area% or less of ferrite and a balance of pearlite, and
wherein the wire rod comprises 8.0×10^4 count/mm^2 or higher of Mo-based carbides.

2. The wire rod for springs of claim 1, further comprising:
one or more elements selected from among V: 0.01 to 0.20%, Ti: 0.01 to 0.15%, and Nb: 0.01 to 0.10% by weight%.

3. The wire rod for springs of claim 1, wherein the Mo-based carbide includes 5 weight% of higher of Mo based on carbide.

4. A method of manufacturing a wire rod for springs with excellent corrosion fatigue resistance, comprising:

heating a billet to 900 to 1100°C, the billet comprising C: 0.40 to 0.70%, Si: 1.30 to 2.30%, Mn: 0.20 to 0.80%, Cr: 0.20 to 0.80%, Cu: 0.01 to 0.40%, Ni: 0.10 to 0.60%, Mo: 0.01 to 0.40%, P: 0.02% or less, S: 0.015% or less, N: 0.01% or less, and a balance of Fe and inevitable impurities by weight% and satisfying equation 1 below:

$$\text{Equation 1: } -0.14 \leq 0.70[Cr] - 0.76[Cu] - 0.24[Ni] \leq 0.47$$

where each element symbol is a value of a content of each element measured by weight%;
obtaining a wire rod by finishing-hot-rolling the heated billet at 800 to 1000°C; and
coiling the wire rod and cooling the wire rod such that the time for maintaining the wire rod at a temperature in a range of 600 to 700°C is to be 31 seconds or longer.

5. The method of claim 4, wherein the billet further comprises one or more elements selected from among V: 0.01 to 0.20%, Ti: 0.01 to 0.15%, and Nb: 0.01 to 0.10% by weight%.

6. A steel wire for springs with excellent corrosion fatigue resistance, comprising:

C: 0.40 to 0.70%, Si: 1.30 to 2.30%, Mn: 0.20 to 0.80%, Cr: 0.20 to 0.80%, Cu: 0.01 to 0.40%, Ni: 0.10 to 0.60%, Mo: 0.01 to 0.40%, P: 0.02% or less, S: 0.015% or less, N: 0.01% or less, and a balance of Fe and inevitable impurities by weight%,
wherein the steel wire satisfies equation 1 below:

$$\text{Equation 1: } -0.14 \leq 0.70[Cr] - 0.76[Cu] - 0.24[Ni] \leq 0.47$$

where each element symbol is a value of a content of each element represented by weight%,
wherein a microstructure is tempered martensite, and
wherein the steel wire comprises 8.0×10^4 count/mm^2 or higher of Mo-based carbides.

7. The steel wire for springs of claim 6, further comprising:
one or more elements selected from among V: 0.01 to 0.20%, Ti: 0.01 to 0.15%, and Nb: 0.01 to 0.10% by weight%.

8. The steel wire for springs of claim 6, wherein the Mo-based carbide comprises 5 weight% or higher of Mo based on carbide.

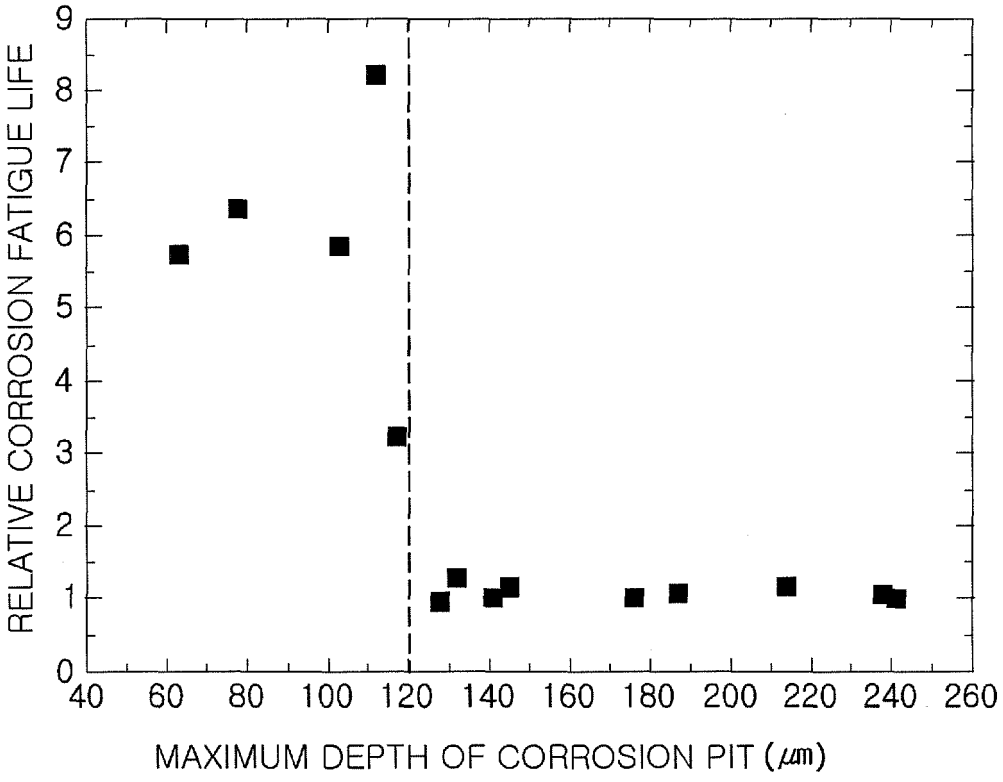
9. The steel wire for springs of claim 6, wherein a maximum depth of a corrosion pit of the steel wire is 120 μm or less.

10. The steel wire for springs of claim 6, wherein tensile strength of the steel wire is 1800MPa or higher.

11. A method of manufacturing a steel wire for springs with excellent corrosion fatigue resistance, comprising:

obtaining the steel wire by drawing a wire rod manufactured by the method in claim 4 or claim 5;
austenitizing the steel wire by heating the steel wire to 850~1000 °C and maintaining the heated steel wire for 1 minute or longer; and
oil-cooling the austenitized wire rod to 25~80°C and tempering the wire rod at 350~500°C.

[FIG. 1]


RELATIVE CORROSION FATIGUE LIFE
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1
2
3
4
5
6
7
8
9
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60
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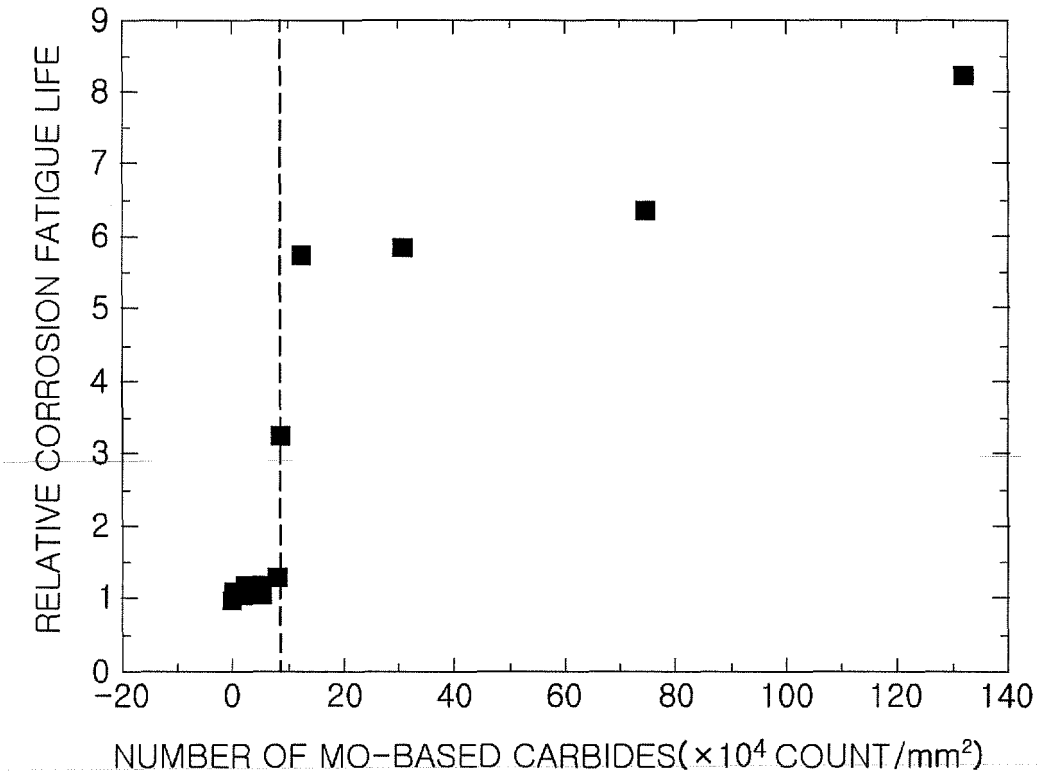
160
180
200
220
240
260
MAXIMUM DEPTH OF CORROSION PIT (μm)

[FIG. 2]


RELATIVE CORROSION FATIGUE LIFE
0
1
2
3
4
5
6
7
8
9
-20
0
20
40
60
80
100
120
140
NUMBER OF MO-BASED CARBIDES(×10⁴ COUNT/mm²)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2017/014232

A. CLASSIFICATION OF SUBJECT MATTER
C22C 38/42(2006.01)i, C22C 38/34(2006.01)i, C22C 38/44(2006.01)i, C22C 38/00(2006.01)i, C21D 8/06(2006.01)i, C21D 9/52(2006.01)i
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C 38/42; C22C 38/06; C22C 38/34; C22C 38/00; C21D 8/06; C21D 8/00; B21B 1/16; C22C 38/44; C21D 9/52

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applications for Utility models: IPC as above
Japanese Utility models and applications for Utility models: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS (KIPO internal) & Keywords: ferrite, perlite, Mo based carbide, corrosion fatigue resistance, wire material for spring, hot rolling

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	JP 2014-122393 A (KOBE STEEL LTD.) 03 July 2014 See paragraphs [0036]-[0052]; and claims 1-10.	1-11
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☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 MARCH 2018 (13.03.2018)	**13 MARCH 2018 (13.03.2018)**

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Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2017/014232

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PCT/KR2017/014232

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