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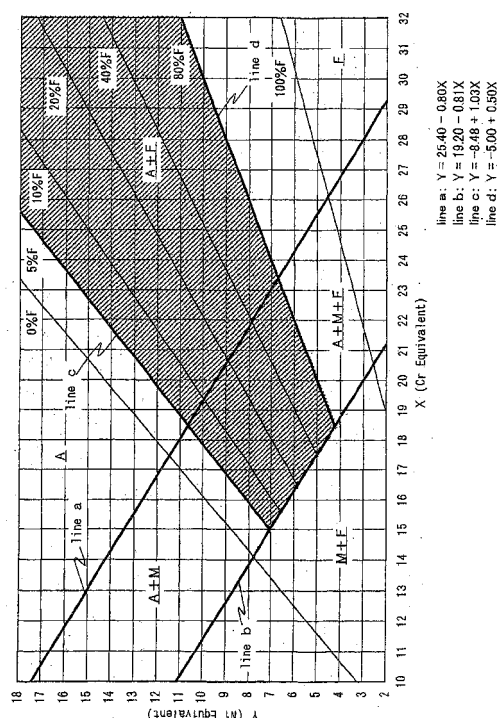
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(54) **HIGH SILICON STAINLESS**

(57) A high-Si stainless steel excellent in various characteristics, inclusive of strength, corrosion resistance, workability and castability, consists of, on the mass % basis, Si: 2 to 5%, Cr: 8 to 25%, Ni: 4 to 16%, Mn: not more than 5%, Cu: not more than 4%, Co: not more than 8%, Mo: not more than 4%, Nb: not more than 3%, Ta: not more than 3%, Ti: not more than 3%, W: not more than 4%, V: not more than 4%, B: not more than 0.01%, Mg: not more than 0.01%, Ca: not more than 0.01%, rare earth elements: not more than 0.01%, the balance being Fe. Impurities in this steel are as follows: C: not more than 0.04%, P: not more than 0.03%, S: not more than 0.02%, Al: not more than 0.03%, N (nitrogen): not more than 0.05%, O (oxygen): not more than 0.005%, and H (hydrogen): not more than 0.0003%.

[FIG. 1]



Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to a high-silicon stainless steel having excellent corrosion resistance and high strength as fundamental characteristics and, in addition, having various characteristics such as fatigue resistance, heat resistance, castability and workability.

BACKGROUND ART

10 **[0002]** Typical metallic materials excellent in corrosion resistance are stainless steels. The field of application of stainless steels covers a wide range and, in recent years, stainless steels are used for not only corrosion resistance material but also various materials that should have characteristics such as mentioned below.

15 (1) Fatigue resistance characteristics

[0003] The uses requiring fatigue resistance are, for example, springs, gears, driving shafts, and the like. A special use is core wires of inter-tooth brush.

20 (2) Heat resistance

[0004] High Cr steels, such as stainless steels, are generally excellent in heat resistance. In addition to such general heat resistance, the resistance against heat check (crack occurring due to thermal stress) is required in particular for rolls for continuous casting equipment, rolls for hot rolling, bearings for use at elevated temperatures, molds for die casting, molds for glass forming, and various heating furnace parts, among others.

(3) Strength, in particular crushing strength

30 **[0005]** Balls, rollers and other parts of bearing systems, supporting plates and rollers in quake-absorbing systems or supporting systems, dies, molds, tools, pressure vessel constituting materials and the like are required to have high crushing strength so that they can carry heavy loads.

(4) Workability, in particular drawability

35 **[0006]** In recent years, the use of thin wires made of an alloy having corrosion resistance and having a diameter of about several tens of micrometers has been increasing. Such wires are used either as such, for example in the case of the above-mentioned core wires of inter-tooth brush or in the form of meshes woven therefrom, for example as filters, screen masks or metal masks or the like. The alloy to be used for the production of such thin wires is required to have excellent drawability (wire drawability).

40 (5) Castability (molten metal fluidity)

[0007] Alloys for making precision casting products thin in thickness and complicated in shape are required to show good fluidity in a molten state on the occasion of casting and producing very few casting defects. Examples of such products are golf club heads, screws, impellers, turbine blades, pumps, valves and the like. When an alloy is used as a welding material, such as welding wire, welding rod, it is required to show good fluidity so that smooth and pretty beads can be formed.

50 (6) Higher level corrosion resistance

[0008] Stainless steels are by nature corrosion-resistant materials. A higher level of corrosion resistance than the level required of ordinary stainless steels is required in the fields of semiconductor device production equipment parts, for example piping and connecting parts, medical instruments, food processing instruments and the like. In the production of semiconductors, high purity gases and pure water are used. Since these must not be contaminated with piping material-derived substances, the piping materials and connecting parts are required to have very good corrosion resistance.

(7) Wear resistance

[0009] Parts for bearing systems, supporting systems and the like, screws for chemical apparatus, various tools and the like are also required to have excellent wear resistance, though common to the property mentioned above (3).

[0010] As mentioned above, metallic materials are required to have various properties and, in many cases, they are required to have several properties simultaneously. For example, the materials for tablet machines (tablet manufacturing machines) used in the pharmaceutical industry are required to have not only high corrosion resistance but also high strength and wear resistance so that the machines can resist deformation and wear during operation.

[0011] On the other hand, for reducing the cost of production of instruments and apparatus, the materials are required to be as inexpensive as possible. This is because the material cost accounts for a great proportion of the total cost in the production of large-sized or mass-produced instruments and apparatus. However, very few materials can meet all of such requirements.

[0012] Iron(Fe)-based stainless steels are materials that are excellent in corrosion resistance and relatively inexpensive. Generally, high strength and good corrosion resistance are properties contradictory to each other in stainless steels. However, there are such stainless steel type alloys as mentioned below that are endowed with both.

(1) Steels according to JIS SUS 440 and 420J2

[0013] These are quench-hardenable stainless steels and are excellent in hardness, strength and wear resistance but are not satisfactory in corrosion resistance. Their hardness can be increased by quenching but strains are readily caused on the occasion of that heat treatment, whereby subsequent finishing works become difficult.

(2) Steels according to JIS SUS 630 and 631

[0014] These are precipitation hardening stainless steels and are easy to work before hardening. Aging treatment provides high levels of hardness, and the corrosion resistance is also good. However, for use in various fields such as mentioned above, further improvements in hardness and corrosion resistance are desired.

(3) High-silicon stainless steel

[0015] This is known through JP Patent No. 619,383 (JP Kokoku S46-9536), JP Patent No. 661,246 (JP Kokoku S47-9899) and JP Patent No. 1,167,791 (JP Kokoku S57-17070), among others, and is called Silicolloy (registered trademark). This steel is an alloy caused to have both high strength (high hardness) and good corrosion resistance by incorporating a relatively large amount of silicon (Si). It is also possible to give age hardenability to this steel by adjusting the chemical composition thereof. The present inventor has been granted a patent (JP Patent No. 2,954,922) on a method of heat treatment of steel products for improving the aging behavior thereof.

[0016] However, even the above-mentioned high-silicon stainless steel cannot yet fully satisfy such various requirements as mentioned above. For example, the above-mentioned piping materials for semiconductor production equipment are themselves required to have a high level of cleanness and, for producing meshes for use as filters, the material is required to have good drawability so that it can be worked into very thin wires. Further, corrosion-resistant metallic materials are used not only as forgings or rolled shapes but also as cast products (castings), hence good castability is also required.

DISCLOSURE OF INVENTION

[0017] The above-mentioned high-silicon stainless steel is a steel having a dual phase structure mainly composed of austenite and ferrite. Owing to its high Si content as compared with ordinary stainless steels, this steel has both corrosion resistance and high strength and shows good fluidity on the occasion of casting. Furthermore, as mentioned above, it can be provided with age hardenability through adjustment of the alloy composition, so that it is also possible to work that steel in a low-strength solid solution state and then causing the same to have high strength by the subsequent aging treatment. The products hardly deform upon aging treatment.

[0018] Therefore, in order to further improve this high-silicon stainless steel that has excellent basic characteristics and thereby further improve the various characteristics mentioned above, the present inventor has completed the present invention.

[0019] A concrete object of the present invention is to markedly improve the characteristics (1) to (7) mentioned above while taking advantage of the basic characteristics of the high-silicon stainless steel mentioned above.

[0020] The present inventor confirmed that the above object could be accomplished by increasing the index of cleanliness of the high-silicon stainless steel. Generally, the index cleanliness of steel means the amount of inclusions,

mainly oxides and sulfides. A steel wherein these inclusions are reduced is referred to as a steel with a high index of cleanliness.

[0021] In the art, measures have been taken to improve corrosion resistance and mechanical properties by reducing the impurities P (phosphorus) and S (sulfur) in steel. It is also known that oxide inclusions can be reduced by reducing the O (oxygen) content in steel. However, for improving various properties of the high-silicon stainless steel, the measures mentioned above alone are not enough.

[0022] The present inventor confirmed that only when not only P, S and O but also C, Al, N (nitrogen) and H (hydrogen) are controlled, the above object can be accomplished.

[0023] The steel according to the present invention is a high-silicon stainless steel having the following chemical composition ("% indicating % by mass"):

Si: 2 to 5%,
Cr: 8 to 25%,
Ni: 4 to 16%,
Mn: not more than 5%,
Cu: not more than 4%,
Co: not more than 8%,
Mo: not more than 4%,
Nb: not more than 3%,
Ta: not more than 3%,
It: not more than 3%,
W: not more than 4%,
V: not more than 4%,
B: not more than 0.01%,
Mg: not more than 0.01%,
Ca: not more than 0.01%, and
rare earth elements: not more than 0.01%, the balance being Fe and impurities, and the contents of C, P, S, Al, N, O and H as impurities being as follows:

C: not more than 0.04%,
P: not more than 0.03%,
S: not more than 0.02%,
Al: not more than 0.03%,
N (nitrogen): not more than 0.05%,
O (oxygen): not more than 0.005%, and
H (hydrogen): not more than 0.0003%.

[0024] A preferred embodiment of the above high-silicon stainless steel is as follows:

A high-silicon stainless steel based on an iron-based alloy comprising:

2.5 to 4.5% of Si,
9 to 20% of Cr,
5 to 15% of Ni,
0.05 to 5% of Mn,
0 to 6% of Co,
0.2 to 4% of Mo,
0 to 1.5% of W
0 to 1.5% of V, and
0 to 0.006% of B, the balance being Fe and impurities, and the contents of C, P, S, Al, N, O and H as impurities being as follows:

C: not more than 0.04%,
P: not more than 0.015%,
S: not more than 0.01%,
Al: not more than 0.01%,
N (nitrogen): not more than 0.03%,
O (oxygen): not more than 0.002%, and

H (hydrogen): not more than 0.0002%.

[0025] For improving the age hardenability, it is desirable that the steel contain at least one of the four components, namely 0.5 to 4% of Cu, 0.1 to 1.5% each of Nb, Ta and Ti, in addition to the above constituents. Further, residues of

[0026] For obtaining a desirable metallographic structure in the steel according to the invention, it is desirable that the contents of the main alloy components be adjusted in the following manner. Thus, the Cr equivalent (X) is defined by the formula (1) given below, and the Ni equivalent (Y) by the formula (2) given below, and adjustments are made so that these X and Y may satisfy the relations (3), (4) and (5) given below.

$$X \text{ (Cr equivalent, \%)} = \text{Cr (\%)} + 0.3 \times \text{Mo (\%)} + 1.5 \times \text{Si (\%)} + 0.5 \times \text{Nb (\%)} \quad (1)$$

$$Y \text{ (Ni equivalent, \%)} = \text{Ni (\%)} + 30 \times \text{C (\%)} + 0.5 \times \text{Mn (\%)} + 0.1 \times \text{Co (\%)} \quad (2)$$

$$Y \geq 19.20 - 0.81 X \quad (3)$$

$$Y \leq -8.48 + 1.03 X \quad (4)$$

$$Y \geq -5.00 + 0.50 X \quad (5)$$

[0027] The above relation (3) represents the region above the straight line b in Fig. 1, the relation (4) the region below the straight line c in Fig. 1, and the relation (5) the region above the straight line d in Fig. 1. Therefore, it is the shaded region in Fig. 1 that satisfies the relations (3), (4) and (5) simultaneously.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028]

Fig. 1 is a graph illustrating the metallographic structure of the high-silicon stainless steel according to the invention.

Fig. 2 and Fig. 3 each is a table showing the chemical compositions of the steels used in testing.

Fig. 4, Fig. 5, Fig. 6 and Fig. 7 each is a table showing the test results.

Fig. 8 is a schematic representation of a crushing test apparatus.

Fig. 9 is a figure illustrating a method of testing for castability (fluidity).

Fig. 10 is a side view (partially in section) illustrating the shape and size of a test specimen for heat check resistance test.

BEST MODES FOR CARRYING OUT THE INVENTION

1. Components of the Steel of the Invention

[0029] In this description "%" concerning the content of alloy component always means "% by mass".

(1) Alloy Components

[0030] The steel of the invention comprises 2 to 8% of Si, 8 to 25% of Cr and 4 to 16% of Ni as essential components.

[0031] Si is not only a main element providing the steel of the invention with strength but also provides the steel with heat resistance, oxidation resistance, corrosion resistance and high-temperature softening resistance as well. It is also an element lowering the melting point of the steel, and increases the fluidity and thereby improves the castability. When its content is below 2%, its effects of improving the above-mentioned characteristics are insufficient. On the other hand, since Si is a potent ferrite-forming element, the addition thereof in an excessive amount disturbs the basic structural balance of the steel of the invention. The upper limit has been set at 5% taking the influence on the Cr equivalent defined by the above formula (1) also into consideration. A more desirable Si content is 2.5 to 4-5%.

[0032] Cr is a component for securing the fundamental characteristics, namely corrosion resistance (in particular

acid resistance), heat resistance and oxidation resistance, of the stainless steel. At below 8.0%, these properties are unsatisfactory. On the other hand, at Cr contents exceeding 25%, the Cr equivalent becomes large, the residual austenite increases and it becomes difficult to attain the desired mechanical properties.

[0033] Ni provides the steel with corrosion resistance, oxidation resistance and heat resistance and, in addition, is an element effective in maintaining the steel matrix in a desirable structural condition (dual phase structure composed of ferrite and austenite or three-phase structure composed of these and martensite) in balance with Cr. For producing these effects, a content of not less than 4% is necessary. However, at levels exceeding 16%, the austenite phase becomes excessive due to the increase in Ni equivalent, with the result that the mechanical properties deteriorate and the economical feature of the steel is lost. A desirable Ni content is 5 to 15%.

[0034] The components which the steel of the invention may contain in addition to the above-mentioned Si, Cr and Ni, namely the optional additive components, are Mn, Cu, Co, Mo, Nb, Ta, Ti, W, V, B, Mg, Ca and rare earth elements (REMs). Only one of these may be added, or two or more of them may be added in combination. The contents of the respective elements are optional provided that they do not exceed the respective upper limits given above. Of course, the content of the element not added becomes substantially 0 (zero) or at the impurity level. In the following, the effects and desirable contents of the above optional additive components are described.

[0035] Mn serves as a deoxidizing agent and at the same time is an austenite forming element. In precipitation hardening stainless steels, Mn does not strongly influence the mechanical properties but serves to making the metallographic structure compact and stabilize the same. However, at levels exceeding 5%, it lowers the corrosion resistance and the Ni equivalent becomes excessive and thereby it becomes difficult to obtain desired mechanical properties. A desirable content is 0.05 to 5%.

[0036] Cu is an element contributing to improvement in corrosion resistance (in particular acid resistance) and to precipitation hardening. However, at levels exceeding 4%, Cu impairs the hot workability of steel, hence the upper limit is 4%. In attempting an improvement in age hardening, a content of 0.5 to 4% is desirable.

[0037] Mo increases the corrosion resistance of steel as well as the strength at elevated temperatures. It also contributes to improvements in toughness and wear resistance. For producing these effects satisfactorily, a content of not lower than 0.2% is desirable. On the other hand, since it is a ferrite forming element, an excessive content thereof leads to an increased Cr equivalent and this makes it difficult to obtain a desired structure. Further, Mo is an expensive element. Therefore, the content of Mo should be not more than 4%.

[0038] Each of Nb, Ta and Ti contributes to increasing the strength of steel through its precipitation hardening effect. In particular, Nb has an effect of increasing the hardened layer depth on the occasion of aging treatment. Therefore, when it is used as a material in thick-walled products, it serves to shorten the aging treatment time. Ta has the same effects as Nb and, in addition, contributes to increasing the hardness in synergy with Cu, without impairing the corrosion resistance. Ti contributes also to improvements in heat resistance and corrosion resistance, in addition to the above-mentioned precipitation hardening effect.

[0039] The effects of the above three components become significant when they are contained each at a level not lower than 0.1%. Therefore, when the age hardenability is to be enhanced, one or more of the four components, namely the above three and Cu, may be selected for addition. However, each of Nb, Ta and Ti causes decreases in hot workability and toughness at a content exceeding 3%, hence the upper limit should be set at 3% for each of them. A desirable content is 0.1 to 1.5% for each.

[0040] Co is an element promoting austenite formation, as indicated by the formula (2) given above. Therefore, it has the effect supplementing the effect of Ni. Further, Co increases the age hardenability and thereby improves the strength (hardness) of products and, in addition, it also contributes to improvement in corrosion resistance. These effects become significant at 0.5% and above and the effects increase as the content increases. However, at an excessive level, the Ni equivalent becomes great and it becomes difficult to secure a desirable structure. Further, Co is an expensive component. Therefore, the upper limit has been set at 8%. When Co is added, its desirable content is 0.5 to 6%.

[0041] W increases the strength of steel at elevated temperatures and improves the creep resistance. At the same atom % level as Mo, it produces almost the same effects, so that it can be used in lieu of Mo or together with Mo. However, when it is added, an addition level up to 4% is sufficient. Considering that W is an expensive element, a desirable content is not higher than 1.5%.

[0042] V increases the precipitation hardenability and serves to improve the strength. It also increases the strength at elevated temperatures and improves the creep resistance. However, when V is excessive, the toughness of steel decreases, so that the content thereof should be suppressed to 4% or below. Desirable content is not higher than 1.5%.

[0043] B is effective in improving the hot workability and improving the toughness at elevated temperatures, among others. However, when B occurs in excess, the hot workability is rather impaired. Therefore, when it is added, it is necessary to suppress its content to 0.01% or below. A desirable content of B is not higher than 0.006%.

[0044] Mg, Ca and rare earth elements such as Y and Ce can be used as deoxidizing agents, desulfurizing agents and the like in the process of refining. These elements are effective in improving the hot workability of steel but, when

they remain in the steel as oxide inclusions, the drawability of the steel is deteriorated. Therefore, even when these are added, their residue contents each should be not higher than 0.01%.

(2) Impurities

[0045] In the following, mention is made of impurity elements. The most characteristic feature of the steel of the invention is that the content of impurity elements is low and, when the contents of the seven elements to be mentioned below are all not higher than the respective specified levels, a steel excellent, on the whole, in the above-mentioned various characteristics can be obtained.

C: not more than 0.04%

[0046] C is an element increasing the strength of steel and, generally, high strength steels contain a certain amount of C as an essential component. However, in the steel of the present invention which contains a large amount of Si, the strength is secured by a specific metallographic structure brought about by Si, hence it is not essential that C be contained. Rather, C is an element lowering the toughness of the steel of the invention and adversely affecting the workability, oxidation resistance and corrosion resistance thereof. Further, C is an element greatly influencing the Ni equivalent, as indicated by the formula (2) given above, so that when it occurs in excess, it becomes difficult to keep a balance with the contents of other components. Therefore, the content of C is recommendably as low as possible.

[0047] Thus, in accordance with the present invention, the content of C is suppressed to 0.04% or below. This is an allowable upper limit but, in the case of non-aging steel, in particular, the C content is desirably suppressed to 0.015% or below. By the current refining technology, it is possible to produce even very low carbon steel with a C content of 0.01% or below.

P: not more than 0.03% (desirably not more than 0.015%)

[0048] P is a typical harmful impurity in stainless steel. It segregates in steel and deteriorates the mechanical properties, workability and corrosion resistance. Therefore, its content should be not more than 0.03% and should be suppressed to a level as low as possible. It is desirable that the content be not higher than 0.015%, preferably not higher than 0.010%.

S: not more than 0.02% (desirably not more than 0.01%)

[0049] S is a harmful element causing red shortness of steel and thereby lowers the hot workability of steel. It also impairs the cleanliness of steel via sulfide inclusions and deteriorates not only the mechanical properties (fatigue strength, curing strength, etc.) but also the corrosion resistance and heat resistance (heat check resistance). Therefore, its content should be suppressed to 0.02% or below, desirably 0.01% or below. In particular in the case of a steel intended for the production of thin wires with a diameter of not greater than 0.1 mm, the content of S is desirably suppressed to 0.005% or below.

Al: not more than 0.03% (desirably not more than 0.01%)

[0050] While Al is used as a deoxidizing agent for steel, the deoxidation product Al_2O_3 markedly deteriorates the cold workability of steel. Therefore, in accordance with the present invention, the allowable upper limit is set at 0.03%. In the case of a steel for thin wire production such as mentioned above, its content is desirably suppressed to 0.01% or below so that good drawability can be secured.

N: not more than 0.05% (desirably not more than 0.03%)

[0051] N is an austenite forming element and, in some instances, it is actively added for stabilizing the austenite phase. However, since the steel of the present invention is required to have good castability as well, N is regarded as an impurity and the upper limit is imposed thereto. When its level exceeds 0.05%, N deteriorates the fluidity of the molten steel and also causes bubble formation, making it difficult to cast thin wall precision castings. It also deteriorates the toughness. In particular when thin castings having a thickness of not more than 2 mm, such as golf club heads or impellers, are produced, the N content is desirably not more than 0.03% and as low as possible.

O: not more than 0.005% (desirably not more than 0.002%)

[0052] O (oxygen) forms oxide inclusions in steel and deteriorates the cleanliness index. Such oxide inclusions lower the deformability of steel and, in particular in drawing, they cause wire breakage and make it impossible to produce thin wires. The occurrence of such inclusions causes deterioration in surface cleanliness of steel products as well as decreases in corrosion resistance, fatigue strength, crushing strength and heat check resistance. Furthermore, they worsen the fluidity in the production of thin castings such as mentioned above. Therefore, the content of O is recommendably as low as possible. Although the allowable upper limit is 0.005%, it is desirable that the O content be further suppressed to 0.02% or less.

H: not more than 0.0003% (desirably not more than 0.0002%)

[0053] H is a very harmful component forming an interstitial solid solution in the matrix ferrite and austenite and causing hydrogen embrittlement. In addition, it causes decreases in toughness, fatigue strength and heat check resistance and, further, adversely affecting the castability. Therefore, the H content should be suppressed to a level as low as possible. While the allowable upper limit is 0.0003% (3 ppm), the H content is desirably not higher than 0.0002% (2 ppm).

(3) Cr Equivalent and Ni Equivalent

[0054] Fig. 1 shows metallographic structures found upon solution heat treatment by water cooling from 1050°C. The abscissa (X axis) denotes the Cr equivalent (Creq) and the ordinate (Y axis) denotes the Ni equivalent (Nieq). The Cr equivalent and Ni equivalent are respectively calculated by the equations (1) and (2) given below.

$$\text{Cr equivalent} = \text{Cr} (\%) + 0.3 \times \text{Mo} (\%) + 1.5 \times \text{Si} (\%) + 0.5 \times \text{Nb} (\%) \quad (1)$$

$$\text{Ni equivalent} = \text{Ni} (\%) + 30 \times \text{C} (\%) + 0.5 \times \text{Mn} (\%) + 0.1 \times \text{Co} (\%) \quad (2)$$

[0055] In Fig. 1, the straight lines a, b, c and d are respectively represented by the equations given below.

$$\text{Straight line a ... } Y = 25.40 - 0.80X$$

$$\text{Straight line b ... } Y = 19.20 - 0.81X$$

$$\text{Straight line c ... } Y = -8.48 + 1.03X$$

$$\text{Straight line d...} Y = -5.00 + 0.50X$$

[0056] Above the straight line a, there is an austenite region or an "austenite + ferrite" region. Below the straight line b, there is a martensite region or a "martensite + ferrite" region. The straight line c indicates the conditions for ferrite to amount to 5%, and the straight line d indicates the conditions for ferrite to amount to 80%.

[0057] The structure of the matrix of the steel of the invention is desirably a dual phase structure comprising 5 to 80% of ferrite with the balance being austenite, or a three-phase structure comprising these two plus a slight proportion of martensite mixed in. Such structure is included in the shaded region in Fig. 1. Therefore, it is understood that by selecting a chemical composition so that the following three relations can be satisfied simultaneously, the above desirable structure can be obtained.

$$Y \geq 19.20 - 0.81 X \text{ (above straight line b)} \quad (3)$$

$$Y \leq -8.48 + 1.03 X \text{ (below straight line c)} \quad (4)$$

$$Y \geq -5.00 + 0.50 X \text{ (above straight line d)} \quad (5)$$

[0058] The structures shown in Fig 1 are structures found upon solution heat treatment. Even after aging treatment, the matrix structures do not show great changes from the states upon solution heat treatment, however. Upon aging treatment, various intermetallic compounds finely precipitate in the matrix and increase the strength (hardness). No problem arrives even when slight changes occur in the structure of the matrix itself.

[0059] The reason why such the above-mentioned dual phase or three-phase structure is desirable as the metallographic structure of the steel of the invention is as follows.

[0060] In austenite single phase steels or substantially austenite single phase steels with ferrite amounting less than 5% (structures above the straight line c in Fig. 1), the required mechanical properties (strength, toughness, wear resistance, etc.) cannot be obtained. With dual phase structures composed of martensite and ferrite (structures above the straight line c in Fig. 1), the strength becomes high but the corrosion resistance is poor. The martensite single phase or martensite-ferrite dual phase structure provides high strength but poor corrosion resistance. Below the straight line d, the amount of ferrite is excessive and the strength and corrosion resistance are insufficient.

[0061] As a result, the region in which good mechanical properties and good corrosion resistance can be obtained is the region surrounded by the straight lines b, c and d, namely the region of dual phase structure composed of 5 to 80% ferrite and austenite or the region of three-phase structures composed of the two with martensite mixed in.

[0062] In Fig. 1, the straight line a corresponds to $Y = 25.40 - 0.80X$ and indicates the critical conditions of martensite formation. In the region below this straight line, namely when the following relation (6) is satisfied, a three-phase structure composed of ferrite + austenite + martensite is formed.

$$Y \leq 25.40 - 0.80X \quad (6)$$

[0063] In particular when a high strength steel is required, not only precipitation hardening but also reinforcement of the matrix itself is desirable. Therefore, it is recommended that the composition adjustment be made so as to satisfy not only the relations (3) to (5) but also the relation (6), namely for the matrix structure to fall within the region below the straight line a in Fig. 1.

2. Process for Producing the Steel of the Invention

(1) Method of melting

[0064] The steel of the present invention can be produced by the conventional method of melting stainless steels. For suppressing the impurity contents at low levels, as mentioned hereinabove, a steel melted in an electric furnace or converter, for instance, is refined by remelting in a vacuum high frequency induction furnace or remelting in a vacuum arc furnace (VAR method) to remove impurity elements. Other refining methods, such as the vacuum electron beam melting method and the electroslag method (ESR method) in a nonoxidizing atmosphere, may also be used. In each case, it is necessary to select melting conditions and subsequent treatment conditions so that the levels of all the impurities mentioned above, from C (carbon) to H (hydrogen), may be reduced to the specified levels or below.

(2) Heat treatment method

[0065] The high-silicon stainless steel according to the present invention includes one having age hardenability and one having no age hardenability. For both, solution heat treatment is essential.

[0066] The age hardenable steel may be used either as solution heat treated or after aging treatment following solution heat treatment for increasing the strength. The steel as solution heat treated is low in strength (low in hardness) and is easy to work and, thus, it is also possible to perform forming in the state as solution heat treated and then conducting aging treatment to raise the strength to a desired level. The aging treatment will not cause deformation of products and therefore is advantageous for the production of products required to have high dimensional precision.

[0067] The solution heat treatment is carried out by heating the alloy at a temperature from 950 to 1150°C and then cooling the same. At temperatures below 950°C, solid solution formation is insufficient and the amount of residual austenite increases, making it difficult to increase the strength. On the other hand, at temperatures exceeding 1150°C, crystal grains become coarse and the toughness decreases. The time of heating is appropriately 1 to 2 hours per inch of product thickness. The method of cooling is not particularly restricted but a rate of cooling at which a solid solution state can be obtained may be secured according to the product size (thickness). Thus, for example, water cooling, oil cooling or air cooling method can be employed.

[0068] The products after this solution heat treatment step have the dual phase structure comprising fine austenite and ferrite or the three-phase structure further comprising martensite, and the hardness is about HRC 34 to 38. Therefore, it is easy to subject the alloy in this solid solution state to machining to the desired shapes of the finished parts.

[0069] The aging treatment is carried out at 200 to 700°C. At low temperatures below 200°C or at high temperatures above 700°C, the desired hardness cannot be obtained. A particularly desirable aging treatment temperature is within the range of 400 to 550°C. By treatment in such temperature range, high levels of hardness not lower than HRC 50 can be obtained. The treatment temperature and treatment time can be selected according to the mechanical properties to be given to the products.

EXAMPLES

1. Materials used

[0070] Thirty-six steels specified in Fig. 2 and Fig. 3 were used as test materials. These steels could be divided into groups of three (e.g. steels Nos. 1 to 3, steels Nos. 4 to 6, ...) and the three in each group were of the same steel group. In the three steels, one marked with Δ is a comparative steel having relatively high impurity levels, one marked with $\bigcirc$ is a steel according to the invention having a high cleanliness index with suppressed impurity levels, and one marked with $\odot$ is a steel according to the invention having an ultrahigh cleanliness index with still further decreased impurity levels. Steels Nos. 34, 35 and 36 are the conventional steels (commercial ones), corresponding to JIS SUS 304, SUS 630 and SUS 420 J2, respectively.

[0071] Each of the above test materials was hot-forged into a round bar with a diameter of 20 mm and this round bar was subjected to solution heat treatment 1 under the conditions shown below. Further, as for the precipitation hardening steels shown in Fig. 2, samples subjected to heat treatment 1 alone and samples subjected to heat treatment 1 and then to aging treatment 2 under the conditions shown below were prepared.

1. Solution heat treatment: 1050°C x 1 hour → water cooling

2. Aging treatment: 480°C x 6 hours → air cooling

Steel No. 34 was subjected to heat treatment according to the above 1 alone, and steel No. 35 to heat treatment according to the above 1 and aging treatment "480°C x 6 hours → air cooling". Steel No. 36 was subjected to quenching heat treatment according to the above 1 and tempering "200°C x 3 hours → air cooling".

2. Mechanical property testing conditions

(1) Tensile test

[0072] Each test material round bar was cut and machined into JIS No. 14 A test specimens for tensile test, which were subjected to tensile test at room temperature on a testing machine according to JIS B 7721. The tensile strength and elongation were determined.

(2) Hardness test

[0073] Each test material round bar was cut to a diameter of 20 mm and a thickness of 10 mm and, after mirror polishing, the hardness was determined on a Rockwell hardness tester.

(3) Impact test

[0074] Each test material round bar was cut and machined into JIS No. 4A V-notched test specimens, and the Charpy impact strength was determined at room temperature using a testing machine according to JIS B 7722.

(4) Fatigue test

[0075] The fatigue test was carried out under the conditions given below, and the fatigue limit after 10^7 stress cycles was determined.

Testing machine: Ono-type rotating bending fatigue tester

Frequency: 2000 rpm

Test temperature: room temperature (in the atmosphere)

Test specimen: diameter 12 mm, length 90 mm, parallel portion diameter 8 mm, parallel portion length 30 mm (R 20)

(5) Crushing test

[0076] Balls 25.4 mm (1 inch) in diameter were cut out of each test material round bar and subjected to crushing strength measurement using an apparatus shown in Fig. 8. The apparatus shown in Fig. 8 has a fixed tool 2 and a movable tool 3 each having a conical indentation and placed in a crushing cylinder 1. The movable tool 3 is hydraulically moved up and down. Two specimens (steel balls) 4 were inserted into this crushing cylinder and the movable tool 3 was pressed down, and the load that caused crushing of the test specimens was recorded.

3. Other tests

[0077] In addition to the above mechanical property tests, the following tests were carried out.

(6) Castability test

[0078] Using a sand-mold having a spiral groove as shown in Fig. 9, the fluidity of the molten steel was examined. In Fig. 9, the groove 6 is 8 mm in width and has a rectangular section with a depth of 7 mm, and has a total length of 1 m. A predetermined amount of each molten steel at 1600°C was poured into this groove through a central sprue 7, and the fluidity of each steel was evaluated in terms of the length of travel of the steel until coagulation. When this distance is longer, the fluidity is better, hence the castability is judged as good.

(7) Drawability test

[0079] Each test material round bar was subjected to hot rolling and cold drawing and, after wire drawing to a diameter of 5.0 mm, further subjected to cold drawing using a diamond die while repeating heat treatment. The drawability was evaluated in terms of the critical diameter allowing wire breakage whereby no more wire drawing was possible. When this value (critical wire diameter) is smaller, the drawability is better. This test was applied to the test specimens (all after the above-mentioned solution heat treatment 1 alone) of steels Nos. 1 to 3 in Fig. 2 and steels Nos. 22 to 30 and 34 in Fig. 3.

(8) Heat check resistance test

[0080] Test specimens 8 having a shape (the shape of a bead on an abacus) as cut out from each test material round bar were surface-polished and subjected to 1000 heating-cooling cycles under the conditions given below and then examined for the occurrence of cracking.

Heating: rapid heating in 6 seconds from room temperature to 750°C, followed by 2 seconds of maintenance at 750°C.

Cooling: water cooling to 25°C in 3 seconds.

[0081] The heat check resistance was evaluated in terms of the number of cracks not shallower than 50 μm.

(9) Corrosion test

[0082] Each test material round bar was cut and machined into a diameter of 15 mm and a thickness of 10 mm, followed by mirror polishing to give test specimens. The surface of each specimen was degreased and washed and immersed in 35% concentrated hydrochloric acid (25°C) for 8 hours. The specimens were then washed, dried, and weighed. The rate of corrosion (g/mm²·hr) was determined from difference between the weight before testing and that after testing.

4. Test results

[0083] The test results are shown in Figs. 4 to 7. For each of all the test results, the ratio of each characteristic value relative to the characteristic value (taken as 1) for the corresponding comparative steel (marked Δ) is also given in italicized bold letters.

[0084] Fig. 4 shows the results of testing of the precipitation hardening steels shown in Fig. 3 in the state of solid solution (without aging treatment), except for castability test results. As is evident from comparison among the test results in each group (group of three steels), the high cleanliness steels (marked by ○) and ultrahigh cleanliness steels (marked by ⊙) according to the invention are superior in all the test items, namely strength, elongation, toughness (Charpy impact values), fatigue strength, castability, heat check resistance and corrosion resistance, to the comparative steels. With the ultrahigh cleanliness steels with the levels of impurities suppressed to particularly low levels, these

improving effects are remarkable.

[0085] Fig. 5 shows the test results of sample materials obtained after further aging treatment following solution heat treatment of the precipitation hardening steels shown in Fig. 2. Here, the difference between the hardness after aging treatment and the hardness (hardness shown in Fig. 4) after solution heat treatment alone is shown for each steel under the heading "hardness difference". The greater this difference is, the greater the precipitation hardenability is.

[0086] After aging treatment as well, all the properties of the high cleanliness steels and ultrahigh cleanliness steels show marked improvements as compared with the comparative steels. Further, comparison between Fig. 4 and Fig. 5 reveals that the tensile strength, hardness, fatigue strength and crushing strength are markedly improved by age treatment.

[0087] In Fig. 6, there are shown the test results of the non-precipitation type steels (steels Nos. 22 to 33) of the invention and the conventional steels (steels Nos. 34 to 36). Among the conventional steels, No. 35 is a precipitation hardening stainless steel, so that, in Test No. 62, the steel after aging treatment was used as the sample material while other sample materials were as obtained after solution heat treatment (No. 63 was subjected to quenching and tempering). Here, too, the high cleanliness steels and ultrahigh cleanliness steels of the invention were found to have greatly superior properties as compared with the comparative steels.

[0088] Fig. 7 shows the results of drawability test of the steels Nos. 1 to 3 shown in Fig. 2 and the steels Nos. 22 to 30 and 34 shown in Fig. 3. All the test samples used were as obtained after solution heat treatment. It can be seen that while the drawability limit was 40 μm for all the comparative steels, all the steels of the invention could be drawn to a diameter of 20 to 30 μm and, in particular, the ultrahigh cleanliness steels were comparable in drawability to SUS 304 (steel No. 34), which has the highest drawability among the conventional stainless steels.

INDUSTRIAL APPLICABILITY

[0089] The high-silicon stainless steel of the present invention has a number of excellent characteristics; as shown in the examples. Therefore, it can be used not only in the same fields of application as the conventional stainless steels but also in novel fields in which the conventional stainless steels cannot be applied. In particular, it is suited for use in those fields where a plurality of properties, such as corrosion resistance, heat resistance, wear resistance and fatigue resistance, are required simultaneously, as in the examples given at the beginning. It is also suited for use in producing very thin steel wires utilizing its excellent workability.

Claims

1. A high-silicon stainless steel consisting of, on the mass % basis, Si: 2 to 5%, Cr: 8 to 25%, Ni: 4 to 16%, Mn: not more than 5%, Cu: not more than 4%, Co: not more than 8%, Mo: not more than 4%, Nb: not more than 3%, Ta: not more than 3%, Ti: not more than 3%, W: not more than 4%, V: not more than 4%, B: not more than 0.01%, Mg: not more than 0.01%, Ca: not more than 0.01%, and rare earth elements: not more than 0.01%, the balance being Fe, wherein the contents of impurities are as follows: C: not more than 0.04%, P: not more than 0.03%, S: not more than 0.02%, Al: not more than 0.03%, N (nitrogen): not more than 0.05%, O (oxygen): not more than 0.005%, and H (hydrogen): not more than 0.0003%.
2. A high-silicon stainless steel consisting of, on the mass % basis, 2.5 to 4.5% of Si, 9 to 20% of Cr, 5 to 15% of Ni, 0.05 to 5% of Mn, 0 to 6% of Co, 0.2 to 4% of Mo, 0 to 1.5% of W, 0 to 1.5% of V, and 0 to 0.006% of B, the balance being Fe and impurities, wherein the contents of impurities are as follows: C: not more than 0.04%, P: not more than 0.015%, S: not more than 0.01%, Al: not more than 0.01%, N (nitrogen): not more than 0.03%, O (oxygen): not more than 0.002%, and H (hydrogen): not more than 0.0002%.
3. A high-silicon stainless steel consisting of, on the mass % basis, 2.5 to 4.5% of Si, 9 to 20% of Cr, 5 to 15% of Ni, 0.05 to 5% of Mn, 0 to 6% of Co, 0.2 to 4% of Mo, 0 to 1.5% of W, 0 to 1.5% of V, 0 to 0.006% of B, and at least one element selected from the group consisting of 0.5 to 4% of Cu, 0.1 to 1.5% of Nb, 0.1 to 1.5% of Ta and 0.1 to 1.5% of Ti, the balance being Fe and impurities, wherein the contents of impurities are as follows: C: not more than 0.04%, P: not more than 0.015%, S: not more than 0.01%, Al: not more than 0.01%, N (nitrogen): not more than 0.03%, O (oxygen): not more than 0.002%, and H (hydrogen): not more than 0.0002%.
4. A high-silicon stainless steel according to Claim 1, 2 or 3, wherein the Cr equivalent (X) defined by the formula (1) given below and the Ni equivalent (Y) defined by the formula (2) given below satisfy the relations (3), (4) and (5) given below:

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$$X \text{ (Cr equivalent, \%)} = \text{Cr (\%)} + 0.3 \times \text{Mo (\%)} + 1.5 \times \text{Si (\%)} + 0.5 \times \text{Nb (\%)} \quad (1)$$

$$Y \text{ (Ni equivalent, \%)} = \text{Ni (\%)} + 30 \times \text{C (\%)} + 0.5 \times \text{Mn (\%)} + 0.1 \times \text{Co (\%)} \quad (2)$$

$$Y \geq 19.20 - 0.81X \quad (3)$$

$$Y \leq -8.48 + 1.03 X \quad (4)$$

$$Y \geq -5.00 + 0.50 X \quad (5)$$

5. A high-silicon stainless steel as claimed in Claim 1, 2 or 3, wherein the Cr equivalent (X) defined by the formula (1) given below and the Ni equivalent (Y) defined by the formula (2) given below satisfy the relations (3), (4), (5) and (6) given below:

$$X \text{ (Cr equivalent, \%)} = \text{Cr (\%)} + 0.3 \times \text{Mo (\%)} + 1.5 \times \text{Si (\%)} + 0.5 \times \text{Nb (\%)} \quad (1)$$

$$Y \text{ (Ni equivalent, \%)} = \text{Ni (\%)} + 30 \times \text{C (\%)} + 0.5 \times \text{Mn (\%)} + 0.1 \times \text{Co (\%)} \quad (2)$$

$$Y \geq 19.20 - 0.81 X \quad (3)$$

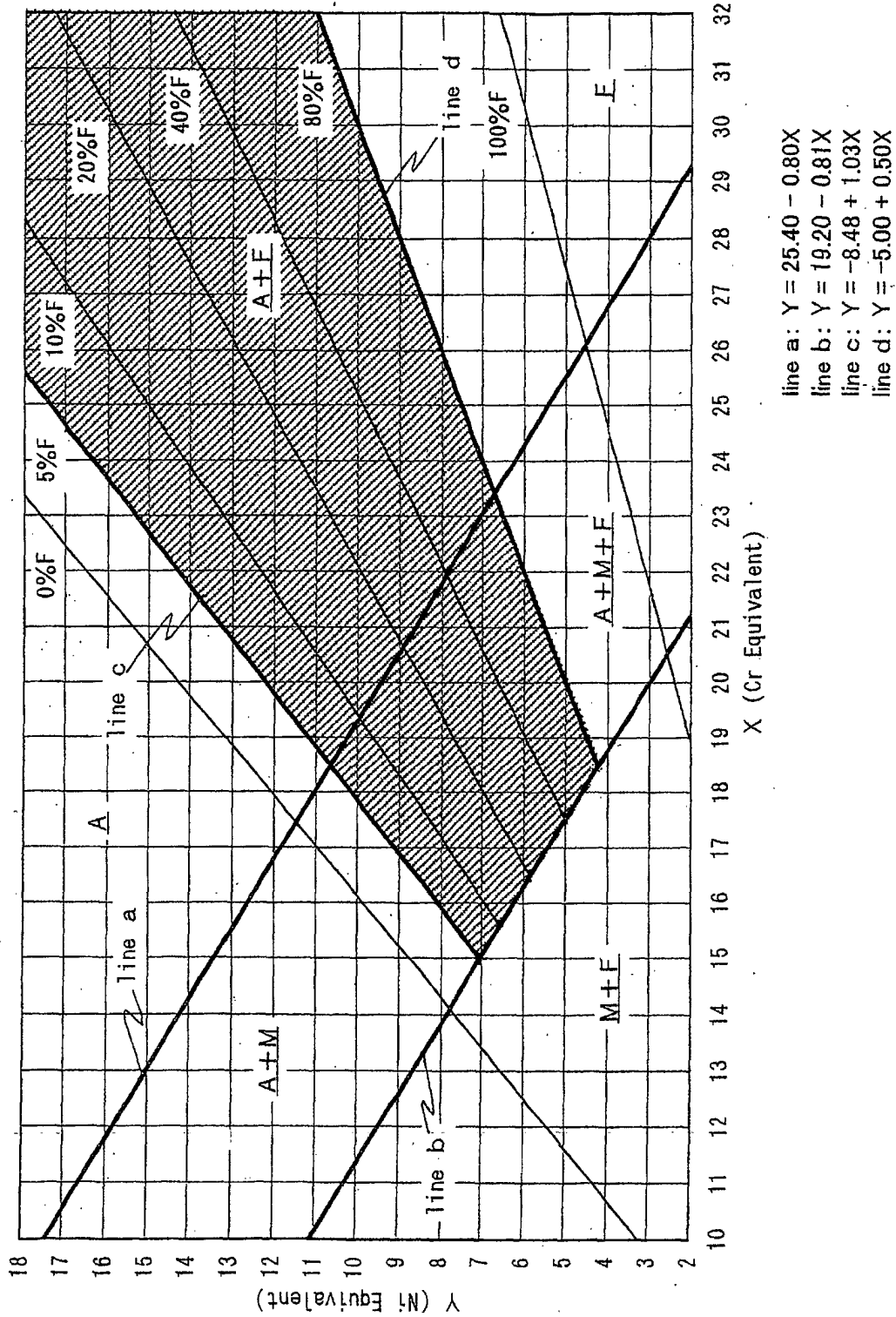
$$Y \leq -8.48 + 1.03X \quad (4)$$

$$Y \geq -5.00 + 0.50 X \quad (5)$$

$$Y \leq 25.40 - 0.80X \quad (6)$$

6. A steel wire having a diameter of not greater than 40 μm produced from the steel according to any of Claims 1 to 5.
7. A part for bearing or supporting equipment or quake-absorbing equipment produced from the steel according to any of Claims 1 to 5.
8. A part for semiconductor production apparatus produced from the steel according to any of Claims 1 to 5.

[FIG. 1]



[FIG. 2]

Steel No.	Chemical Composition (mass %)																			
	C	Si	Mn	Cu	Ni	Cr	Mo	Nb	Co	Ti	Ta	W	V	B	P	S	Al	N	O	H
1 △	17.00	7.98	0.033	3.73	0.88	0.997	6.55	11.00	0.71	0.38					0.034	0.029	0.035	0.0529	0.0105	0.00045
2 ○	16.15	7.67	0.021	3.35	1.03	1.060	6.52	10.78	0.39	0.46					0.027	0.015	0.025	0.0348	0.0048	0.00028
3 ⊙	15.99	7.56	0.013	3.26	0.84	1.030	6.75	10.80	0.37	0.37					0.010	0.004	0.005	0.0138	0.0018	0.00016
4 △	16.21	8.51	0.032	3.57	0.98	1.050	6.55	10.37	1.61		5.13	0.68	0.73		0.032	0.024	0.032	0.0522	0.0095	0.00039
5 ○	16.60	7.96	0.016	3.65	0.94	1.010	6.51	10.68	1.48		4.95	0.69	0.74		0.024	0.018	0.021	0.0370	0.0044	0.00021
6 ⊙	16.25	7.75	0.004	3.58	1.06	1.030	6.60	10.41	1.56		5.00	0.67	0.65		0.012	0.003	0.006	0.0123	0.0018	0.00011
7 △	16.75	8.39	0.031	2.52	0.93	2.110	6.54	12.54	0.72	0.42	4.52	0.72	0.74		0.031	0.022	0.033	0.0505	0.0079	0.00043
8 ○	16.78	8.45	0.032	2.56	0.95	2.040	6.56	12.51	0.74	0.41	4.53	0.71	0.78		0.024	0.017	0.015	0.0341	0.0049	0.00025
9 ⊙	16.68	8.39	0.030	2.47	0.90	2.080	6.58	12.53	0.77	0.43	4.57	0.74	0.71		0.011	0.005	0.008	0.0183	0.0015	0.00007
10 △	16.71	7.48	0.032	1.93	0.95	1.200	6.04	13.11	1.55	0.47		1.21	0.72		0.034	0.024	0.034	0.0515	0.0112	0.00039
11 ○	16.91	7.40	0.030	2.12	0.93	1.110	6.03	13.08	1.51	0.40		1.21	0.77		0.024	0.019	0.022	0.0305	0.0046	0.00021
12 ⊙	17.00	7.47	0.029	2.21	0.99	1.070	6.10	13.02	1.53	0.41		1.22	0.73		0.011	0.004	0.006	0.0148	0.0017	0.00009
13 △	16.42	8.46	0.033	3.62	0.97	2.040	6.52	10.60	0.54	0.45	4.62	1.23	1.17		0.033	0.022	0.036	0.0556	0.0095	0.00038
14 ○	16.43	8.43	0.031	3.66	0.93	2.220	6.57	10.57	0.53	0.42	4.61	1.25	1.13		0.025	0.014	0.011	0.0306	0.0042	0.00025
15 ⊙	16.27	8.42	0.030	3.58	0.97	2.050	6.58	10.48	0.58	0.49	4.58	1.27	1.05		0.010	0.004	0.006	0.0122	0.0015	0.00008
16 △	16.57	7.94	0.032	3.65	0.96	3.100	6.50	10.55	0.59	0.74		1.37			0.032	0.022	0.040	0.0511	0.0088	0.00051
17 ○	16.24	7.91	0.030	3.55	0.94	3.130	6.54	10.39	0.54	0.73		1.34			0.026	0.016	0.014	0.0346	0.0040	0.00021
18 ⊙	16.39	7.81	0.028	3.59	0.91	3.070	6.51	10.47	0.57	0.72		1.29			0.014	0.007	0.008	0.0168	0.0014	0.00010
19 △	16.73	7.91	0.031	3.63	0.90	3.110	6.53	10.90	0.55	0.44		1.24	0.71		0.034	0.023	0.038	0.0524	0.0108	0.00040
20 ○	16.68	7.88	0.029	3.64	0.93	3.140	6.54	10.82	0.61	0.43		1.22	0.77		0.020	0.016	0.015	0.0332	0.0038	0.00022
21 ⊙	16.81	7.93	0.030	3.60	1.04	2.980	6.51	11.04	0.54	0.41		1.23	0.75		0.011	0.002	0.007	0.0190	0.0016	0.00011

Precipitation Hardening Steel

【FIG. 3】

Steel No.	Chemical Composition (mass %)															
	C	Si	Mn	Cu	Ni	Cr	Mo	Nb	Co	Ti	Ta	W	V	B	P	S
22 △	0.47	0.32	3.86	2.05	1.060	6.48	16.10	0.51							0.035	0.028
23 ○	0.11	0.020	3.75	2.05	1.060	6.48	16.10	0.51							0.022	0.012
24 ⊙	0.01	0.008	3.66	2.44	1.090	6.55	16.00	0.58							0.012	0.004
25 △	0.37	0.034	4.03	1.73	1.830	9.48	18.53	1.71						0.0042	0.032	0.026
26 ○	0.54	0.019	4.04	1.94	1.570	9.00	18.94	1.51						0.0043	0.019	0.014
27 ⊙	0.00	0.010	4.01	2.02	1.630	8.69	19.08	1.23						0.0040	0.007	0.003
28 △	0.98	0.037	4.01	1.39	0.070	14.05	17.60	0.67	1.220						0.031	0.027
29 ○	0.15	0.018	4.22	1.39	0.180	13.74	20.35	2.04	1.700						0.023	0.016
30 ⊙	0.86	0.007	4.19	0.96	0.050	14.04	17.82	0.95	1.280						0.006	0.005
31 △	0.10	0.031	4.23	1.63	0.120	14.15	24.33	1.13	2.070			1.26	0.62		0.039	0.026
32 ○	0.25	0.020	4.17	1.59	0.080	12.64	22.43	1.02	2.160			1.15	0.64		0.025	0.014
33 ⊙	0.26	0.013	3.87	1.44	0.088	13.95	20.56	0.99	1.960			1.32	0.71		0.010	0.003
34	0.22	0.050	0.38	1.09		8.17	18.46								0.033	0.023
35	0.20	0.050	0.25	0.89		4.25	15.59		0.370						0.035	0.006
36	0.20	0.360	0.49	0.42		0.19	12.60								0.032	0.015

【FIG. 4】

Test No.	Steel No.	Tensile Strength (N/mm ²)	Elongation (%)	Hardness (HRC)	Charpy Impact Value (J/cm ²)	Fatigue Strength (Fatigue Limit) (N/mm ²)	Crush Strength (Crush Load) (ton)	Castability (Running Length) (mm)	Heat Check Resistance (Number of Cracks)	Corrosion Rate (g/m ² · hr)
1	1	1110	22	35	165	356	38	580	78	73.6587
2	2	1185	25	34	185	527	65	681	62	63.4578
3	3	1254	28	35	195	698	78	882	41	52.3679
4	4	1150	18	38	155	366	40	288	65	15.4368
5	5	1224	20	38	164	542	69	342	53	12.4478
6	6	1280	23	39	171	705	83	445	34	10.2213
7	7	1121	16	37	151	361	39	269	68	14.3258
8	8	1180	18	38	155	536	64	321	56	11.2248
9	9	1265	20	38	162	703	81	401	37	9.5684
10	10	1050	20	35	171	405	38	204	72	13.6879
11	11	1081	22	36	175	583	63	251	53	11.3325
12	12	1110	24	37	186	776	78	325	37	8.6587
13	13	1202	16	36	162	382	36	197	69	26.8793
14	14	1230	19	37	165	556	61	233	55	20.5987
15	15	1263	21	38	178	712	78	298	39	16.5987
16	16	1210	18	36	155	396	37	204	76	45.3583
17	17	1235	19	38	164	573	68	241	51	37.6548
18	18	1260	22	39	175	786	85	312	62	29.5855
19	19	1262	18	37	156	423	42	201	70	43.6879
20	20	1280	19	38	160	613	72	239	53	35.2478
21	21	1307	19	40	172	825	89	305	37	28.5479

【FIG. 5】

Test No.	Steel No.	Tensile Strength (N/mm ²)	Elongation (%)	Hardness (HRC)	Difference of Hardness* (HRC)	Charpy Impact Value (J/cm ²)	Fatigue Strength (Fatigue Limit) (N/mm ²)	Crush Strength (Crush Load) (ton)	Corrosion Rate (g/m ² · hr)
22	1 △	1606	15	52	17	10	432	58	109.8827
23	2 ○	1650	17	52	18	16	670	121	91.6524
24	3 ◎	1684	18	52	17	31	867	135	75.3489
25	4 △	1750	6	58	20	8	432	65	17.7657
26	5 ○	1783	8	58	20	12	662	131	14.9875
27	6 ◎	1835	11	59	20	16	864	142	11.2235
28	7 △	1745	2	60	23	6	432	68	22.4869
29	8 ○	1753	2	60	22	8	657	134	18.1938
30	9 ◎	1768	3	61	23	8	860	148	13.2579
31	10 △	1749	2	59	24	5	479	60	21.5319
32	11 ○	1757	3	60	24	7	721	125	17.4255
33	12 ◎	1764	3	60	23	8	953	139	12.3698
34	13 △	1780	1	60	24	4	446	67	40.3689
35	14 ○	1802	1	61	24	4	628	136	32.2564
36	15 ◎	1815	2	61	23	5	904	149	24.1398
37	16 △	1760	1	59	23	4	468	66	68.1358
38	17 ○	1782	2	60	22	4	704	136	53.2664
39	18 ◎	1805	2	60	21	5	938	147	42.2579
40	19 △	1785	1	60	23	4	498	57	66.5684
41	20 ○	1802	1	60	22	4	749	130	54.2368
42	21 ◎	1813	1	61	21	4	964	146	39.2364

(*) : Difference between the hardness after aging and the hardness before aging

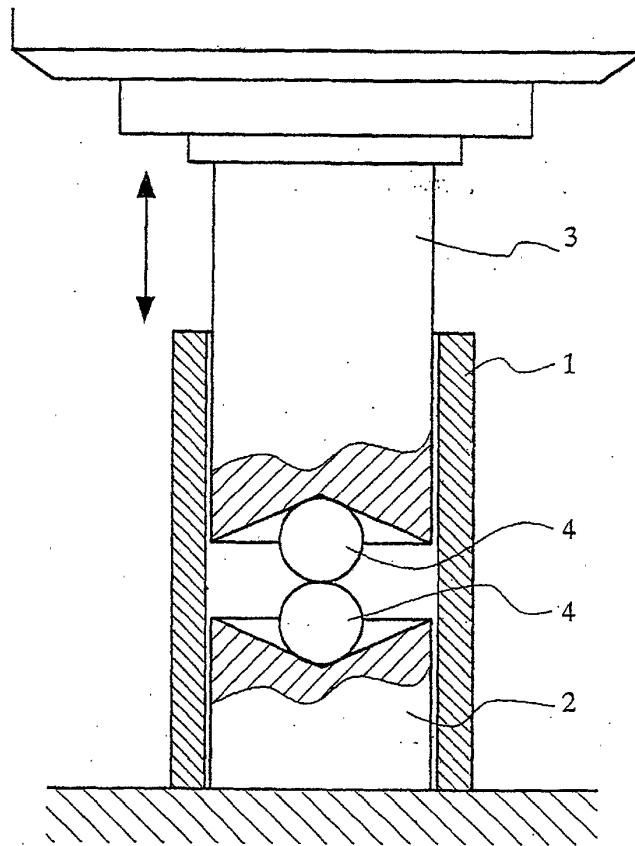
【FIG. 6】

Test No.	Steel No.	Tensile Strength (N/mm ²)	Elongation (%)	Hardness (HRC)	Charpy Impact Value (J/cm ²)	Fatigue Strength (Fatigue Limit) (N/mm ²)	Crush Strength (Crush Load) (ton)	Castability (Running Length) (mm)	Heat Check Resistance (Number of Cracks)	Corrosion Rate (g/m ² · hr)
49	22 △	825	45	24	225	184	13	568	61	32.5647
50	23 ○	830	46	25	236	280	25	668	45	26.5871
51	24 ⊙	845	48	25	252	429	32	847	31	21.6983
52	25 △	786	44	21	235	172	11	625	54	15.6950
53	26 ○	790	46	21	240	250	23	758	42	13.2478
54	27 ⊙	810	47	22	251	395	29	932	26	10.8712
55	28 △	743	69	10	350	145	5	600	32	21.8984
56	29 ○	755	69	11	364	210	9	714	26	18.5475
57	30 ⊙	765	72	11	372	304	12	887	15	14.9984
58	31 △	720	69	8	345	122	4	543	30	19.4768
59	32 ○	735	70	9	355	190	8	653	22	16.4578
60	33 ⊙	744	71	9	362	293	11	820	13	12.6698
61	34	635	58	8	161	170	8	218		260.3955
62	35	1410	16	45	25	590	42	206		94.9642
63	36	1686	2	52	4.9		53	198	285	324.1940

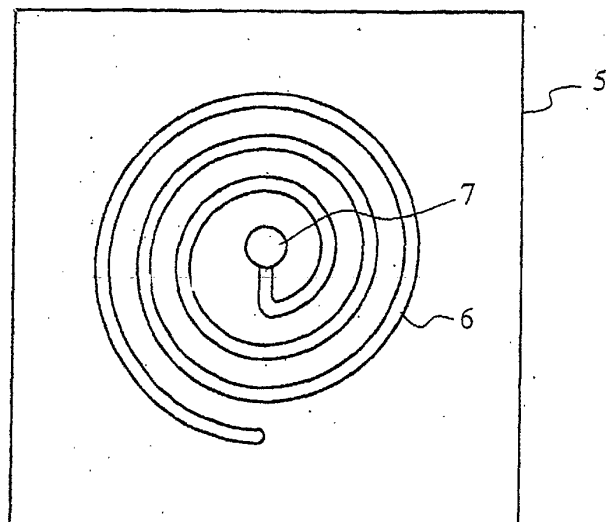
【FIG. 7】

Test No.	Steel No.		Drawability (Drawable Diameter) (μm)
64	1	Δ	40
65	2	$\bigcirc$	30
66	3	$\odot$	20
67	22	Δ	40
68	23	$\bigcirc$	30
69	24	$\odot$	20
70	25	Δ	40
71	26	$\bigcirc$	30
72	27	$\odot$	20
73	28	Δ	40
74	29	$\bigcirc$	30
75	30	$\odot$	20
76	34		20

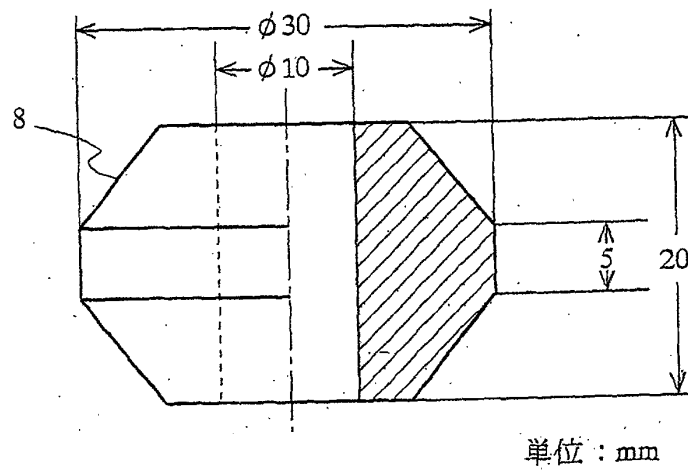
【FIG. 8】



【FIG. 9】



【FIG. 10】



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP00/08877

A. CLASSIFICATION OF SUBJECT MATTER Int.Cl ⁷ C22C 38/00, 38/40, 38/58		
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) Int.Cl ⁷ C22C 38/00-38/58		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1926-1996 Toroku Jitsuyo Shinan Koho 1994-2001 Kokai Jitsuyo Shinan Koho 1971-2001 Jitsuyo Shinan Toroku Koho 1996-2001		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) DERWENT WPI		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP, 11-256308, A (Sumikin Stainless Kokan K.K.), 21 September, 1999 (21.09.99) (Family: none)	1-8
A	JP, 11-211046, A (Nisshin Steel Co., Ltd.), 06 August, 1999 (06.08.99) (Family: none)	1-8
A	EP, 434887, A (Nisshin Steel Co., Ltd.), 03 July, 1991 (03.07.91) & JP, 3-191039, A (Nisshin Steel Co., Ltd.), 21 August, 1991 (21.08.91) (Family: none)	1-8
A	JP, 9-302446, A (Daido Steel Co., Ltd.), 25 November, 1997 (25.11.97) (Family: none)	1-8
A	JP, 9-316602, A (Sumitomo Metal Mining Co., Ltd.), 09 December, 1997 (09.12.97) (Family: none)	1-8
☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "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 "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "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 13 March, 2001 (13.03.01)		Date of mailing of the international search report 27 March, 2001 (27.03.01)
Name and mailing address of the ISA/ Japanese Patent Office		Authorized officer
Facsimile No.		Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)