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(54) **DUPLEX STAINLESS STEEL WIRE MATERIAL, STEEL WIRE, BOLT, AND METHOD OF MANUFACTURING THE SAME**

DRAHTMATERIAL AUS ROSTFREIEM DUPLEXSTAHL, STAHL DRAHT, BOLZEN UND VERFAHREN ZU DESSEN HERSTELLUNG

MATÉRIAU POUR FIL D'ACIER INOXYDABLE DUPLEX, FIL D'ACIER, BOULON ET PROCÉDÉ DE FABRICATION ASSOCIÉ

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Description

TECHNICAL FIELD

[0001] The present invention relates to a duplex stainless steel wire which has excellent cold forgeability and can provide, at low cost, for example, high strength bolts having corrosion resistance equivalent to SUS304.

[0002] The present invention also relates to a soft duplex stainless steel wire material which is magnetizable and has excellent cold workability, and to a soft duplex stainless steel wire material which has excellent cold workability, is magnetizable, and is capable of providing, at low cost, strong cold worked components such as screws, pins, wire gauze, wire, rope, and springs having corrosion resistance equivalent to SUS304 or SUS316.

BACKGROUND ART

[0003] In the past, an SUS304 wire material has generally been used for high strength, highly corrosion resistant bolts having strength at the 700 N/mm² level. However, in recent years, the automobile and consumer electronics industries have spurred demand for stronger (and more lightweight) bolts. Furthermore, the high content of expensive Ni in SUS304 bolts and the resulting high cost has led to strong demand for a lower cost product.

[0004] In the past, demand for stronger bolts was met, for example, by SUS630 bolts of martensite stainless steel (for example, see Patent Document 1).

[0005] However, although SUS630 bolts have excellent strength, corrosion resistance is inadequate and cold forgeability also suffers greatly, leading to greatly increased production costs, which significantly limits the use of such bolts.

[0006] In addition, low-cost high strength bolts with excellent manufacturability made of an approximately 13% Cr-based martensite stainless steel have also been proposed (see Patent Document 2). However, such bolts have inadequate corrosion resistance, which limits their use.

[0007] Furthermore, high strength bolts made of austenite stainless steel with high (C+N) content have also been proposed (see Patent Document 3). However, the inferior cold forgeability of such bolts means significantly higher production costs, limiting commercial uptake.

[0008] On the other hand, in recent years, low-Ni duplex stainless steels which limit the use of expensive Ni have been proposed (Patent Documents 4 to 6).

[0009] However, because conventional duplex stainless steel has poor cold forgeability and high production costs, bolts made of duplex stainless steel have been unavailable commercially.

[0010] As described above, among existing stainless steel bolts and stainless steel wire materials heretofore used as bolts, no product can claim to combine high corrosion resistance, high strength, high cold forgeability, and low cost.

[0011] Products for which corrosion resistance is required, such as screws, pins, wire netting and wire, have heretofore been manufactured using austenite stainless steel wire material such as SUS304 or SUSXM7, by severe cold processes such as drawing, cold forging and bending. In contrast to press molding of steel sheets, which demands materials with high elongation characteristics, cold working of a wire material requires softness and a high reduction of area at tensile fracture (high elongation characteristics are not a requirement). In terms of the tensile strength of the wire material, this softness requires a value of 700 N/mm² or less, and preferably 650 N/mm² or less.

[0012] However, a disadvantage of austenite-based stainless steel products is that because large quantities of expensive Ni are added, the resulting products are expensive despite the inexpensive manufacturing process.

[0013] Furthermore, the non-magnetic nature of austenite-based stainless steel leads to further inconvenience, including poor workability due to tools not being able to adhere to close a fastener, or the inability of magnetic sensors to detect when the material used in a wire netting or mesh (particularly in a conveyor belt or the like used with foodstuffs) falls into and contaminates a food item.

[0014] For products that require magnetizability and corrosion resistance, ferrite-based stainless steel wire materials have been proposed which have low amounts of C and N, and added Nb (see Patent Documents 7 to 9).

[0015] However, production costs for these materials are high due to the inadequate corrosion resistance of the cold-worked products, as well as the tendency for surface flaws to occur during rolling of high Cr-based wire material.

[0016] On the other hand, in recent years, a number of varieties of modestly priced duplex stainless steels with reduced Ni have been proposed (see Patent Documents 10 to 12).

[0017] In Patent Document 10, a high strength duplex stainless steel is disclosed that has an excellent Young's modulus and low Ni content, and contains 0.04% or more nitrogen to enhance strength. However, in excess of 1% of Si and 0.04% or more of nitrogen are added in order to enhance the strength, and the examples disclose a high strength steel exceeding 80 kg/mm², showing that no consideration is given to achieving softness and a high reduction of area at tensile fracture, meaning that in real terms, cold working of the wire material is problematic.

[0018] In Patent Document 11, a duplex stainless steel containing low Ni and not less than 0.05% of nitrogen is disclosed which is corrosion resistant and has favorable weldability. However, no disclosure is made regarding cold

workability, and with the preferred range for the nitrogen content reported as 0.06% to 0.12% in order to enhance the strength, and the steel (low Si steel) disclosed in an example containing not less than 0.13% of nitrogen, no consideration is given to achieving softness and a high reduction of area at tensile fracture, meaning that in real terms, cold working of the wire material is problematic.

[0019] In Patent Document 12, a low-Ni high strength duplex stainless steel which contains not less than 0.05% nitrogen and has excellent relaxation properties is disclosed. However, the examples disclose steels containing not less than 0.13% nitrogen in order to enhance the strength, showing that no consideration is given to achieving softness and a high reduction of area at tensile fracture, meaning that in real terms, cold working of the wire material is problematic.

[0020] In Patent Document 13, a low-Ni duplex stainless steel which contains not less than 0.05% of nitrogen and has excellent ductility and deep drawability is disclosed. However, the examples disclose steels that contain not less than 0.08% of strength-enhancing nitrogen in order to enhance stretching and improve the deep drawability of the steel sheet, showing that no consideration is given to achieving softness and a high reduction of area at tensile fracture, meaning that in real terms, cold working of the wire material is problematic.

[0021] As described above, of the stainless steels heretofore available, none have the softness and high reduction of area at tensile fracture required for cold working of wire materials, while also demonstrating high corrosion resistance and magnetizability at low cost.

[0022]

Patent Document 1: Japanese Unexamined Patent Application, First Publication No. Hei 9-314276

Patent Document 2: Japanese Unexamined Patent Application, First Publication No. 2005-179718

Patent Document 3: Japanese Unexamined Patent Application, First Publication No. 2006-274295

Patent Document 4: PCT International Publication No. WO2005/073422

Patent Document 5: Japanese Patent (Granted) Publication No. 3,271,262

Patent Document 6: European Patent Application No. EP0337846

Patent Document 7: Japanese Patent (Granted) Publication No. 2,906,445

Patent Document 8: Japanese Patent (Granted) Publication No. 2,817,266

Patent Document 9: Japanese Unexamined Patent Application, First Publication No. 2006-16665

Patent Document 10: Japanese Unexamined Patent Application, First Publication No. Sho 62-47461

Patent Document 11: Japanese Unexamined Patent Application, First Publication No. Sho 61-56267

Patent Document 12: Japanese Unexamined Patent Application, First Publication No. Hei 2-305940

Patent Document 13: Japanese Unexamined Patent Application, First Publication No. 2006-169622

EP 1 715 073 A1 discloses a low Ni and high N austenitic-ferritic stainless steel having high formability and punch stretchability.

EP 337 846 A1 relates to an austenitic-ferritic stainless steel having high corrosion resistance and formability, with low Mo and high Cu contents.

A ferritic-austenitic stainless steel excellent in corrosion resistance and workability and a process for manufacturing the same is also disclosed in the earlier, not prepublished E 2 172 574 A1.

DISCLOSURE OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0023] An object of the present invention is to provide a low-cost austenite-ferrite duplex steel wire for producing high strength and highly corrosion resistant bolts, to provide steel wire and bolts and a method for their manufacture, and to impart cold forgeability and enhance the strength of bolt products by controlling the composition, constituent elements,

and material properties of a low-cost corrosion resistant duplex stainless steel wire .

[0024] Another object of the present invention is to provide a low-cost duplex stainless steel wire material with magnetic properties which offers excellent cold workability and corrosion resistance, to significantly lower the production costs of cold-worked products in comparison to conventional austenite stainless steel wire materials, and to impart magnetizability.

MEANS TO SOLVE THE PROBLEMS

[0025] As a result of various investigations conducted with a view to achieving the above objects, the inventors of the present invention discovered that by reducing the amount of expensive Ni contained in a highly corrosion resistant duplex stainless steel, performing component adjustment to stabilize the composition (at a low M value), controlling the ferrite phase to yield a high volume fraction, and optimizing the tensile strength of the wire material and steel wire through heat treatment and drawing, favorable cold forgeability and a high strength bolt product could both be achieved at a low cost.

[0026] In addition, the inventors of the present invention discovered that, from a base of a corrosion resistant duplex stainless steel comprising a magnetic ferrite phase and an austenite phase, by reducing the amount of expensive Ni and performing component adjustment to control the composition (M value control), and suppressing work hardening by lowering (C+N), a low-cost corrosion resistant duplex stainless steel wire material could be imparted with significantly greater cold workability.

[0027] The present invention is based on these findings, and adopts the aspects described below.

[0028] Disclosed herein - but not within the claims - is an austenite-ferrite duplex stainless steel wire material containing, in terms of mass %:

C: 0.005 to 0.05%,
Si: 0.1 to 1.0%,
Mn: 0.1 to 10.0%,
Ni: 1.0 to 6.0%,
Cr: 19.0 to 30.0%,
Cu: 0.05 to 3.0%, and
N: 0.005 to 0.20%,

with the remainder being Fe and substantially unavoidable impurities, wherein a C+N content is 0.20% or less, an M value represented by formula (a) below is 60 or less, an F value represented by formula (b) below is 45 to 85, and a tensile strength is 550 to 750 N/mm².

$$M = 551 - 462(C+N) - 9.2Si - 8.1Mn - 29(Ni+Cu) - 13.7Cr - 18.5Mo \quad (a)$$

$$F = 5.6Cr - 7.1Ni + 2.4Mo + 15Si - 3.1Mn - 300C - 134N - 26.6 \quad (b)$$

[0029] A first aspect of the present invention is an austenite-ferrite duplex stainless steel wire consisting of, in terms of mass %:

C: 0.005 to 0.05%,
Si: 0.1 to 1.0%,
Mn: 0.1 to 10.0%,
Ni: 1.0 to 6.0%,
Cr: 19.0 to 30.0%,
Cu: not less than 0.2%, but less than 1.0%,
N: 0.005 to 0.20%,

optionally one or more selected from Mo: not more than 1.0%, B: not more than 0.01%, Al: not more than 0.1%, Mg: not

more than 0.01%, and Ca: not more than 0.01%, Nb: not more than 0.1%, Ti: not more than 0.5%, V: not more than 1.0%, and Zr: not more than 1.0%

with the remainder being Fe and substantially unavoidable impurities, wherein a C+N content is 0.20% or less, an M value represented by formula (a) below is 60 or less, an F value represented by formula (b) below is 45 to 85, and a tensile strength is 700 to 1000 N/mm².

$$M = 551 - 462(C+N) - 9.2Si - 8.1Mn - 29(Ni+Cu) - 13.7Cr - 18.5Mo \quad (a)$$

$$F = 5.6Cr - 7.1Ni + 2.4Mo + 15Si - 3.1Mn - 300C - 134N - 26.6 \quad (b)$$

[0030] A second aspect of the present invention is a high strength and highly corrosion resistant bolt composed of the steel wire material according to the first aspect, wherein the tensile strength is within a range from 700 to 1,200 N/mm².

[0031] A third aspect of the present invention is a method of manufacturing a high strength and highly corrosion resistant bolt, the method including subjecting an austenite-ferrite duplex stainless steel wire composed of the steel wire material according to the first aspect and having a tensile strength of 700 to 1,000 N/mm² to cold bolt forming, and then performing an aging heat treatment at 300 to 600°C for 1 to 100 minutes.

[0032] A fourth aspect of the present invention is a magnetizable soft duplex stainless steel wire material containing, in terms of mass %:

C: 0.005 to 0.05%,

Si: 0.1 to 1.0%,

Mn: 0.1 to 10.0%,

Ni: 1.6 to 6.0%,

Cr: 19.0 to 30.0%,

Cu: 0.05 to 3.0%,

N: at least 0.005% but less than 0.06%,

optionally one or more selected from Mo: not more than 3.0%, B: not more than 0.01%, Al: not more than 0.1%, Mg: not more than 0.01%, and Ca: not more than 0.01%, Nb: not more than 0.1%, Ti: not more than 0.5%, V: not more than 1.0%, and Zr: not more than 1.0%

with the remainder being Fe and substantially unavoidable impurities, wherein a C+N content is 0.09% or less, an M value represented by formula (a) below is 60 or less, a tensile strength is 700 N/mm² or less, and a reduction of area at tensile fracture is 70% or more.

$$M = 551 - 462(C+N) - 9.2Si - 8.1Mn - 29(Ni+Cu) - 13.7Cr - 18.5Mo \quad (a)$$

EFFECT OF THE INVENTION

[0033] The duplex stainless steel wire of the present invention, which exhibits excellent cold forgeability and is used for forming high strength and highly corrosion resistant bolts, despite not containing expensive Ni in large quantities, allows excellent cold forgeability to be secured while offering high corrosion resistance and high strength equivalent to or better than SUS304, and thus enables high strength and highly corrosion resistant bolts to be provided at low cost.

[0034] The soft duplex stainless steel wire material with excellent cold workability according to the present invention, despite not containing expensive Ni in large quantities, allows excellent cold workability to be secured while offering magnetizability as well as corrosion resistance equivalent to austenite stainless steel such as SUS304 and SUS316, thus enabling a magnetizable highly corrosion resistant product to be provided at low cost.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035]

FIG. 1 is a graph illustrating the relationship between the F value and the volume fraction of the ferrite phase of a wire material product.

FIG. 2 is a graph illustrating the relationship between the processing ratio (%) of the wire material (15% drawn material) and the compressive deformation stress (N/mm²) with respect to F values.

BEST MODE FOR CARRYING OUT THE INVENTION

[0036] As follows is a description of the reasons for the restrictions specified in the first to third aspect of the present invention.

[0037] The C content is not less than 0.005% to ensure the strength of the bolt product. However, if the C content exceeds 0.05%, then not only are Cr carbonitrides produced which adversely affect the corrosion resistance, but cold forgeability also deteriorates, and consequently the C content is restricted to not more than 0.05%. Preferably, the C content does not exceed 0.03%.

[0038] The N content is not less than 0.005% to ensure strengthening of the bolt product by solid solution strengthening and age hardening. However, if the N content exceeds 0.20%, cold forgeability deteriorates significantly. Therefore, the maximum N content is 0.20%. Preferably, the N content is less than 0.05%.

[0039] The C+N content, for the above reasons related to cold forgeability, is restricted to not exceeding 0.20%. Preferably, C+N content is not exceeding 0.10%.

[0040] The Si content is not less than 0.1 %, for deoxidation purposes. However, if the Si content exceeds 1.0%, cold forgeability deteriorates. Therefore, the maximum Si content is 1.0%. The preferred range is from 0.2 to 0.6%.

[0041] The Mn content is not less than 0.1%, for deoxidation purposes and as an adjustment to obtain a stable austenite structure. However, if the Mn content exceeds 10.0%, rust resistance and the ferrite volume fraction are reduced, tensile strength increases, and cold forgeability deteriorates. Therefore, the maximum Mn content is restricted to 10.0%. The preferred range is from 0.5 to 5.0%.

[0042] Ni content is not less than 1.0% to stabilize the austenite structure and secure cold forgeability. However, if the Ni content exceeds 6.0%, then the effects achieved reach saturation, the volume fraction of the ferrite phase reaches 45% or less, and the cold forgeability (tool life) deteriorates. The economic viability also suffers due to the high cost of Ni. Therefore, the maximum Ni content is restricted to 6.0%. The preferred range is more than 3.0% but not exceeding 5.0%.

[0043] In order to ensure favorable corrosion resistance, increase the volume fraction of the ferrite phase, and stabilize the austenite structure to ensure cold forgeability, the Cr content is not less than 19.0%. However, if the Cr content exceeds 30.0%, then because the effects thereof reach saturation and the volume fraction of the ferrite phase conversely exceeds 85%, the strength of the bolt product is reduced. Therefore, the maximum Cr content is restricted to 30.0%. The preferred range is from 22.0 to 26.0%.

[0044] Cu is effective in stabilizing the austenite structure, improving the cold forgeability by suppressing work hardening, and promoting age hardening of the ferrite phase during aging treatment after cold forging, thereby increasing the strength of the bolt product. Therefore, the Cu content is not less than 0.2% but less than 1.0%.

[0045] The M value represented by formula (a) below is an indicator that contributes to the stability of the austenite phase, and is disclosed in "Testu to Hagane", vol. 63(1977), page 772. When the M value is high, a rigid work-induced martensite phase is produced. When cold-forging a duplex stainless steel, if the M value exceeds 60, then a rigid work-induced martensite phase is produced during cold forging, and the cold forgeability deteriorates markedly (tool life is adversely affected and cracking occurs during cold forging). Therefore, the M value is restricted to 60 or less, and in a preferred range does not exceed 40.

$$M = 551 - 462(C+N) - 9.2Si - 8.1Mn - 29(Ni+Cu) - 13.7Cr - 18.5Mo \quad (a)$$

[0046] The F value represented by formula (b) below is an indicator that contributes to the volume fraction of the ferrite phase, and is disclosed in Japanese Examined Patent Application, Second Publication No. Hei 7-74416. A higher F value indicates an increased ferrite phase. FIG. 1 examines the volume fraction of the ferrite phase of the duplex stainless steel wire material product at various F values. If the F value is 45 or higher, then the volume fraction of the ferrite phase reaches 45 vol.% or more, which indicates high yield strength and low work hardening characteristics (FIG. 2), allows a high product strength (the tensile strength of the bolt shaft) in the order of 700 to 1,200 N/mm² to be obtained, and

ensures favorable cold forgeability of the head portion. Therefore, the F value is restricted to not less than 45. As shown by the relationship between the processing ratio (%) and the compressive deformation stress (N/mm²) with respect to F values in FIG. 2. when the F value is less than 45, significant work hardening occurs, and the cold forgeability (in terms of rolling cracks and tool damage) deteriorates markedly. On the other hand, if the F value exceeds 85, then the soft ferrite phase exceeds 85%, and the high-strength austenite phase is reduced, which conversely decreases the strength of the bolt product. Therefore, the maximum F value is 85. The preferred range is from 50 to 80.

$$F = 5.6Cr - 7.1Ni + 2.4Mo + 15Si - 3.1Mn - 300C - 134N - 26.6 \quad (b)$$

[0047] The tensile strength of the herein disclosed - but not claimed - wire material contributes significantly to its cold forgeability, and when the tensile strength of the wire material is less than 550 N/mm², the strength of cold-forged products such as bolts is low, giving a less worthwhile high strength product. Therefore, the minimum tensile strength is restricted to 550 N/mm². On the other hand, when the tensile strength of the wire material exceeds 750 N/mm², the cold forgeability (in terms of rolling cracks and tool damage) tends to deteriorate markedly. Therefore, the maximum tensile strength is restricted to 750 N/mm². The preferred range is from 600 to 700 N/mm².

[0048] Mo is an element that is effective in improving corrosion resistance, and this effect can be achieved in a stable manner by adding 0.1% or more of Mo. However, if the Mo content exceeds 1.0%, not only do material costs rise, but hardening of the materials occurs and the cold forgeability deteriorates. Accordingly, the maximum Mo content is restricted to 1.0%. The preferred range is not less than 0.2% but less than 0.5%.

[0049] B is an element that is effective in improving hot workability, and this effect can be achieved in a stable manner by adding 0.001% or more of B. However, if the B content exceeds 0.01%, borides are produced, adversely affecting the corrosion resistance and cold forgeability. Therefore, the maximum B content is restricted to 0.01%. The preferred range is from 0.002% to 0.006%.

[0050] Al, Mg, and Ca are effective for deoxidation, and this effect can be achieved in a stable manner by adding one or more of Al: not less than 0.005%, Mg: not less than 0.001%, and Ca: not less than 0.001%. However, if the Al, Mg and Ca content exceeds 0.1%, 0.01% and 0.01% respectively, then the effects thereof reach saturation, and adversely coarse oxides (inclusions) are produced, which can cause cracking during cold forging. Therefore, the maximum Al, Mg and Ca content is restricted to 0.1%, 0.01%, and 0.01%, respectively. The preferred ranges for these elements are one or more of Al: 0.01 to 0.06%, Mg: 0.002 to 0.005%, and Ca: 0.002 to 0.005%.

[0051] Nb, Ti, V, and Zr are effective for ensuring corrosion resistance by suppressing the formation of Cr carbonitrides, and this effect can be achieved in a stable manner by adding one or more of Nb: not less than 0.05%, Ti: not less than 0.02%, V: not less than 0.05%, and Zr: not less than 0.05%. However, if the Nb, Ti, V, and Zr content exceeds 1.0%, 0.5%, 1.0 and 1.0% respectively, the effects thereof reach saturation, and adversely coarse precipitates are produced, which can cause cracking during cold forging. Therefore, the maximum amount of each element is restricted. The preferred ranges for these elements are one or more of Nb: 0.1 to 0.6%, Ti: 0.05 to 0.5%, V: 0.1 to 0.6%, and Zr: 0.1 to 0.6%.

[0052] Ordinarily, steel contains oxygen inherent to the manufacturing process as an unavoidable impurity, but in the present invention, the steel preferably contains not more than 0.01% oxygen as an unavoidable impurity.

[0053] A drawn steel wire is produced by subjecting the wire material to wire drawing, but the tensile strength of the steel wire contributes significantly to the cold forgeability and the strength of the bolt product, and if the tensile strength of the steel wire is less than 700 N/mm², then the strength of the bolt product is reduced, giving a less worthwhile high strength product. Therefore, the minimum tensile strength is restricted to 700 N/mm². On the other hand, when the tensile strength of the steel wire exceeds 1,000 N/mm², the cold forgeability deteriorates markedly (tool life is adversely affected and cracking occurs during cold forging). Therefore, the maximum tensile strength is restricted to 1,000 N/mm². The preferred range is from 700 to 900 N/mm².

[0054] The tensile strength of the high strength bolt of the present invention is strengthened by the aging heat treatment performed after wire drawing and cold forging. At this time, if the tensile strength of the bolt product is less than 700 N/mm², the bolt product is less worthwhile as a high strength bolt product. On the other hand, if the tensile strength of the bolt product exceeds 1,200 N/mm², costs related to cold forging increase markedly due to cracking during cold forging and tool damage and the like. Therefore, the maximum tensile strength of the bolt product is restricted to 1,200 N/mm². The preferred range for demonstrating economic effectiveness is from 800 to 1,000 N/mm².

[0055] After cold forging is performed to form bolts from the steel wire of the present invention, an effective means of improving the tensile strength of the bolt product is to perform aging heat treatment at not less than 300°C for not less than 1 minute. On the other hand, temperatures exceeding 600°C result in overaging, which reduces the tensile strength of the bolt product. Therefore the maximum temperature is limited to 600°C. The preferred temperature range is from 400 to 550°C. Furthermore, with aging times exceeding 100 minutes, not only do the effects of the age hardening reach saturation, but in some cases overaging causes the tensile strength of the bolt product to decrease. Therefore, the

maximum aging time is restricted to 100 minutes. The preferred range for the aging time is from 5 to 60 minutes.

[0056] As follows is a description of the reasons for the restrictions specified in the fourth aspect of the present invention.

[0057] C is added in an amount of not less than 0.005% to ensure the strength of the steel. However, if the C content exceeds 0.05%, not only does the cold workability deteriorate, but Cr carbonitrides are also produced which adversely affect the corrosion resistance. Consequently, the maximum C content is restricted to 0.05%. The preferred range is from 0.01 to 0.03%.

[0058] N is added in an amount not exceeding 0.005% to ensure the strength of the cold-worked product by solid solution strengthening. However, if N is added in an amount of 0.06% or more, the tensile strength increases and the cold workability deteriorates. Therefore, the maximum amount of N is less than 0.06%. Ordinarily, not less than 0.06% of N is added to duplex stainless steels in order to minimize the use of expensive alloying elements, but a characteristic of the steel of the present invention is that the composition and component balance are controlled and the N content is kept low to dramatically improve the cold workability of the soft wire material. The preferred range is not less than 0.02% but less than 0.05%.

[0059] The C+N content, for the above reasons related to cold workability, is restricted to 0.09% or less. Preferably, the C+N content does not exceed 0.07%.

[0060] Si is added in an amount of not less than 0.1% to effect deoxidation. However, if Si is added in an amount exceeding 1.0%, the steel hardens and the cold workability deteriorates. Therefore, the maximum Si content is 0.1%. The preferred range is from 0.2% to 0.6%.

[0061] Mn is added in an amount of not less than 0.1% in order to effect deoxidation and obtain a duplex ferrite-austenite structure, and as an adjustment to stabilize the austenite structure. However, if Mn is added in an amount exceeding 10.0%, the corrosion resistance and strength rise which adversely affects the cold workability. Therefore, the maximum Mn content is 10.0%. The preferred range is from 0.5% to 5.0%.

[0062] Ni is added in an amount of not less than 1.6% in order to lower the M value and obtain a ferrite-austenite structure, and to stabilize the austenite structure to ensure favorable cold workability. However, if the amount of added Ni exceeds 6.0%, the effects thereof reach saturation, and economic viability suffers because Ni is an expensive element. Therefore, the maximum Ni content is restricted to 6.0%. The preferred range is from 2.0% to 5.0%.

[0063] Cr is added in an amount of not less than 19.0% in order to ensure corrosion resistance and obtain a ferrite-austenite duplex structure, and to stabilize the austenite structure to ensure favorable cold workability. However, if the amount of added Cr exceeds 30.0%, the effects thereof reach saturation, and adversely, the cold workability deteriorates. Therefore, the maximum Cr content is restricted to 30.0%. The preferred range is from 20.0% to 26.0%.

[0064] Cu is added in an amount of not less than 0.05% in order to lower the M value and obtain a ferrite-austenite structure, stabilize the austenite structure, and suppress work hardening, thereby improving the cold workability. However, because a Cu content exceeding 3.0% exceeds the solid solubility limit of Cu and causes a marked deterioration in the hot workability of the material, the maximum Cu content is restricted to 3.0%. The preferred range is less than 1.0%.

[0065] The M value represented by formula (a) below is an indicator that contributes to the stability of the austenite phase, and is disclosed in "Testu to Hagane", vol. 63(1977), page 772. When the M value is high, a rigid work-induced martensite phase is produced. When cold-forging a duplex stainless steel, if the M value exceeds 60, then a rigid work-induced martensite phase is produced during cold working, and the cold forgeability deteriorates markedly. Therefore, the M value is restricted to 60 or less, and in a preferred range does not exceed 40.

$$M = 551 - 462(C+N) - 9.2Si - 8.1Mn - 29(Ni+Cu) - 13.7Cr - 18.5Mo \quad (a)$$

[0066] The tensile strength of the wire material contributes significantly to its cold workability, and when the tensile strength of the wire material exceeds 700 N/mm², the cold workability deteriorates markedly. Therefore, the maximum tensile strength is restricted to 700 N/mm². On the other hand, when the tensile strength of the wire material is less than 500 N/mm², the strength of the cold-forged product is too low, making the resulting product less viable. Therefore, preferably, the minimum tensile strength is restricted to 500 N/mm². The preferred range is from 500 to 650 N/mm².

[0067] The reduction of area at tensile fracture properties of the wire material contribute significantly to the cold workability of the wire material, and when the reduction of area at tensile fracture is less than 70%, the workability of cold processes such as cold drawing and cold forging deteriorates. Therefore, the reduction of area at tensile fracture is limited to not less than 70%. The preferred range is not less than 75%.

[0068] Magnetizability is a feature not inherent to austenite stainless steel, and for reasons including improving workability by offering magnetizability with respect to the magnetic tools used to close fasteners, and allowing magnetic sensors to detect when a material used as a wire netting or mesh (particularly in a conveyor belt or the like used with foodstuffs) falls into and contaminates a food product, magnetizability is a significant feature in industrial terms. Therefore, the degree of magnetizability is specified in the present invention. The relative magnetic permeability is preferably not

less than 3.0.

[0069] Mo is an element that is effective in improving the corrosion resistance, and this effect can be achieved in a stable manner by adding 0.1% or more of Mo. However, if Mo is added in an amount exceeding 3%, then the material undergoes hardening, and sigma phase precipitation occurs, causing a marked deterioration in the cold workability. Accordingly, the maximum Mo content is restricted to 3%. The preferred range is from 0.3% to 1.0%.

[0070] B is an element that is effective in improving the hot workability, and this effect can be achieved in a stable manner by adding 0.001% or more of B. However, if the B content exceeds 0.01%, borides are produced, adversely affecting the corrosion resistance and cold workability. Therefore, the maximum B content is restricted to 0.01%. The preferred range is from 0.002% to 0.006%.

[0071] Al, Mg, and Ca are effective for deoxidation, and this effect can be achieved in a stable manner by adding one or more of Al: not less than 0.005%, Mg: not less than 0.001%, and Ca: not less than 0.001%. However, if the Al, Mg and Ca content exceeds 0.1%, 0.01% and 0.01% respectively, the effects thereof reach saturation, and adversely coarse oxides (inclusions) are produced, resulting in poor cold workability. Therefore, the maximum content of Al, Mg, and Ca is restricted to 0.1%, 0.01% and 0.01%, respectively. The preferred ranges for these elements are one or more of Al: 0.008 to 0.06%, Mg: 0.001 to 0.005%, and Ca: 0.001 to 0.005%.

[0072] Nb, Ti, V, and Zr are effective for ensuring corrosion resistance by suppressing the formation of Cr carbonitrides, and this effect can be achieved in a stable manner by adding one or more of Nb: not less than 0.01%, Ti: not less than 0.01%, V: not less than 0.01%, and Zr: not less than 0.01%. However, if the Nb, Ti, V and Zr content exceeds 1.0%, 0.5%, 1.0 and 1.0% respectively, the effects thereof reach saturation, and adversely coarse precipitates are produced, resulting in poor cold workability. Therefore, the maximum amount of each element is restricted. The preferred ranges for these elements are one or more of Nb: 0.05 to 0.6%, Ti: 0.05 to 0.5%, V: 0.1 to 0.6%, and Zr: 0.05 to 0.6%.

[0073] Ordinarily, steel contains oxygen inherent to the manufacturing process as an unavoidable impurity, but in the present invention, the steel preferably contains not more than 0.01% oxygen as an unavoidable impurity.

EXAMPLE 1

[0074] Example 1 of the present invention is described below.

[0075] Tables 1 through 4 show the chemical composition of the steels according to example 1.

Table 1

Steel	Chemical composition (mass%)													C+N	M value	F value
	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Al	O	N	Other			
A	0.02	0.5	3.6	0.024	0.001	4	23.5	0.0	0.4	-	0.006	0.04	-	0.06	39.2	60.4
B	0.04	0.6	4.2	0.038	0.001	4.2	23.5	0.0	0.5	-	0.006	0.06	-	0.1	6.3	49.7
C	0.01	0.6	4.1	0.024	0.001	4	23.8	0.0	0.4	-	0.006	0.16	-	0.17	-20.7	49.0
D	0.01	0.5	4.1	0.022	0.001	4.1	23.4	0.0	0.4	-	0.005	0.01	-	0.02	52.1	64.6
E	0.02	0.2	2.1	0.026	0.002	5.5	24	0.0	0.3	-	0.005	0.04	-	0.06	6.7	53.0
F	0.02	0.8	2	0.025	0.001	5.5	24	0.0	0.3	-	0.005	0.04	-	0.06	2.0	62.4
G	0.02	0.6	9.7	0.024	0.001	1.8	25.5	0.0	0.5	-	0.005	0.03	-	0.05	27.0	70.9
H	0.02	0.7	5.5	0.021	0.003	3.5	26	0.0	0.5	-	0.005	0.04	-	0.06	-0.7	74.8
I	0.01	0.5	1.1	0.032	0.003	5.8	25.4	0.0	0.4	-	0.006	0.06	-	0.07	-23.4	66.4
J	0.02	0.9	9.8	0.023	0.001	1.9	21.2	0.0	0.8	-	0.005	0.06	-	0.08	56.9	45.3
K	0.02	0.3	1.9	0.026	0.003	5.7	25.6	0.0	0.8	-	0.005	0.04	-	0.06	-34.8	61.2
L	0.02	0.3	1.9	0.027	0.002	5.5	29.2	0.0	0.4	-	0.005	0.04	-	0.06	-66.8	84.0
M	0.01	0.5	2.1	0.033	0.006	3.5	24.1	0.0	0.5	-	0.005	0.04	-	0.05	59.4	74.7
N	0.01	0.5	2.1	0.033	0.003	3.5	24	0.0	1.5	-	0.006	0.04	-	0.05	31.8	71.0
Steel of the present invention																
*																

* not within the composition defined in claim 1

Table 2

Steel	Chemical composition (mass%)													C+N	M value	F value
	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Al	O	N	Other			
*	0.01	0.4	1.9	0.032	0.008	3.4	24.2	0.0	2.6	-	0.007	0.04	-	0.05	2.6	68.6
P	0.02	0.5	1.7	0.032	0.001	5.4	23.2	0.3	0.4	-	0.005	0.06	-	0.08	4.1	52.7
Q	0.02	0.4	1.8	0.022	0.002	5.3	22.8	0.9	0.4	-	0.005	0.06	-	0.08	1.5	50.8
R	0.02	0.5	2.2	0.027	0.001	4	24.5	0.1	0.7	-	0.005	0.1	B; 0.005	0.12	0.1	61.5
S	0.02	0.5	2.3	0.028	0.001	5.4	24.5	0.1	0.7	0.035	0.003	0.05	-	0.07	-18.4	57.9
T	0.01	0.6	1.9	0.026	0.002	4	25	0.1	0.6	-	0.005	0.16	Mg; 0.003	0.17	-25.5	62.0
U	0.02	0.4	2.2	0.026	0.002	4	25.5	0.1	0.5	-	0.005	0.15	Ca; 0.005	0.17	-30.2	59.5
V	0.02	0.5	2	0.027	0.002	4.2	25.1	0.1	0.6	0.02	0.005	0.13	Ca; 0.003	0.15	-23.7	60.4
W	0.01	0.4	2.1	0.026	0.002	4.4	24.2	0.1	0.7	-	0.005	0.11	Nb; 0.4	0.12	-5.9	57.4
X	0.03	0.5	2.2	0.032	0.003	4.5	24.3	0.1	0.4	-	0.005	0.05	Ti; 0.3	0.08	15.5	61.4
Y	0.02	0.4	2.1	0.025	0.003	4.1	23.1	0.1	0.7	-	0.006	0.05	V; 0.6	0.07	41.4	58.4
Z	0.03	0.6	1.8	0.023	0.003	4.1	22.8	0.1	0.5	-	0.006	0.04	Zr; 0.4	0.07	51.5	59.6
AA	0.02	0.6	1.7	0.023	0.003	4.5	23	0.1	0.6	-	0.005	0.04	Nb; 0.1, V; 0.1	0.06	39.7	60.9
BBB	0.02	0.4	1.8	0.030	0.002	4.1	24.1	0.2	0.4	0.03	0.004	0.04	B; 0.003	0.06	40.7	67.6
CCC	0.02	0.3	1.9	0.028	0.003	4.0	24.2	0.1	0.3	0.03	0.004	0.05	Nb; 0.08, B; 0.002	0.07	42.4	65.7
DDD	0.01	0.4	1.8	0.025	0.002	3.9	23.8	0.1	0.5	0.02	0.003	0.04	Ca; 0.002	0.05	54.1	69.7
EEE	0.02	0.3	1.7	0.031	0.001	4.2	24.1	0.1	0.4	0.03	0.004	0.05	V; 0.12	0.04	36.7	64.1
Steel of the present invention																

* not within the composition defined in claim 1

Table 3

Steel	Chemical composition (mass%)													C+N	M value	F value
	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Al	O	N	Other			
AB	<u>0.07</u>	0.5	4.2	0.025	0.002	4.9	23.2	0.0	0.3	-	0.005	0.12	-	0.19	-44.8	<u>25.1</u>
AC	0.02	0.5	4.1	0.026	0.001	5.1	23.5	0.0	0.3	-	0.005	<u>0.22</u>	-	<u>0.24</u>	-76.8	<u>27.2</u>
AD	0.03	<u>1.3</u>	4.2	0.018	0.001	4.9	22.9	0.0	0.4	-	0.005	0.04	-	0.07	4.5	57.8
AE	0.03	0.7	<u>11.5</u>	0.033	0.005	4.9	23.2	0.0	0.7	-	0.004	0.04	-	0.07	-61.9	<u>26.9</u>
AF	0.04	0.7	4.7	0.022	0.003	<u>0.8</u>	23.1	0.0	0.6	-	0.004	0.13	-	0.17	<u>70.1</u>	61.8
AG	0.02	0.7	4.8	0.022	0.003	<u>0.7</u>	23.5	0.0	0.6	-	0.004	0.03	-	0.05	<u>122.2</u>	83.9
AH	0.02	0.5	4.4	0.024	0.003	<u>6.5</u>	23.3	0.0	0.5	-	0.006	0.11	-	0.13	-72.3	<u>29.4</u>
AI	0.02	0.4	4.5	0.025	0.002	<u>7.4</u>	23.5	0.0	0.8	-	0.006	0.04	-	0.06	-77.2	<u>30.7</u>
AJ	0.02	0.5	5.1	0.032	0.003	4.3	<u>18.1</u>	0.0	0.3	-	0.005	0.08	-	0.10	<u>76.8</u>	18.4
AK	0.02	0.6	3.8	0.023	0.003	4.3	<u>30.5</u>	0.0	0.5	-	0.005	0.04	-	0.06	-70.8	<u>98.1</u>
AL	0.01	0.6	4.1	0.025	0.002	5.1	23.5	0.0	3.2	-	0.004	0.04	-	0.05	-74.2	46.9
Comparative steel																

* Underlines indicate values or results outside of the ranges specified by the present invention.

Table 4

Chemical composition (mass%)																		
Steel	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Al	O	N	Other	C+N	M value	F value		
AM	0.02	0.7	3.9	0.026	0.001	4.9	22.9	1.8	0.7	-	0.005	0.04	-	0.06	-24.2	56.1		
AN	0.02	0.5	4.1	0.025	0.002	5	24.5	0.0	0.5	-	0.006	0.11	<u>B; 0.023</u>	0.13	-42.8	47.7		
AO	0.03	0.5	4.2	0.032	0.004	4.9	24.5	0.0	0.7	<u>0.22</u>	0.005	0.09	-	0.12	-41.9	47.2		
AP	0.02	0.7	4.1	0.028	0.003	4.9	24.5	0.0	0.6	-	0.006	0.12	<u>Mg; 0.015</u>	0.14	-49.2	49.8		
AQ	0.02	0.6	3.9	0.03	0.002	5.1	24.4	0.0	0.4	-	0.007	0.09	<u>Ca; 0.018</u>	0.11	-31.4	51.5		
AR	0.02	0.5	4	0.031	0.002	5.1	24.3	0.0	0.5	-	0.005	0.08	<u>Nb; 1.3</u>	0.1	-28.2	50.2		
AS	0.03	0.7	4.2	0.032	0.003	5.1	24.3	0.0	0.5	-	0.004	0.09	<u>Ti; 0.8</u>	0.12	-40.9	48.2		
AT	0.02	0.7	4.3	0.027	0.002	4.8	24.3	0.0	0.5	-	0.005	0.09	<u>V; 1.8</u>	0.11	-28.4	53.1		
AU	0.03	0.6	3.9	0.027	0.003	4.9	24.3	0.0	0.3	-	0.006	0.09	<u>Zr; 1.5</u>	0.12	-26.0	49.7		
AV	0.02	0.4	3.1	0.026	0.002	3.7	22.4	0.0	0.2	-	0.005	0.06	-	0.08	<u>64.5</u>	54.4		
AW	<u>0.06</u>	0.6	1.9	0.026	0.003	<u>8.1</u>	<u>18.5</u>	0.0	0.4	-	0.005	0.06	-	0.12	-26.0	<u>-4.6</u>		
Comparative steel																		

* Underlines indicate values or results outside of the ranges specified by the present invention.

[0076] Steels having these chemical compositions were each melted in a 300 kg vacuum melting furnace and cast into a $\varnothing 80$ mm steel slab, the resulting steel slab was then subjected to a hot wire rod rolling process to reduce the diameter to $\varnothing 5.5$ to 6.5 mm, and after completing hot rolling at 1050°C, the resulting product was maintained at 1050°C for 5 minutes by inline heat treatment, subjected to solution treatment in the form of water cooling, and then acid-washed to obtain a wire material product. Thereafter, an oxalic acid film treatment was performed, and light drawing was performed by a cold process to $\varnothing 5.2$ mm, thus preparing a steel wire for cold forging.

[0077] Subsequently, cold forging and form rolling were performed to produce approximately 5000 units of hex bolts. The bolts were then selectively subjected to aging treatment at 300 to 650°C for 3 to 200 minutes. Finally, all of the bolts were subjected to barrel finishing and washing, thus completing preparation of a hex bolt product.

[0078] Evaluations were conducted by evaluating the tensile strength of the steel wire, the volume fraction of the ferrite phase of the steel wire, the cold forgeability (whether cracks or tool defects occur), the tensile strength of the bolt product, and the corrosion resistance. The results of these evaluations are shown in Tables 5 to 8.

Table 5

Category	No.	Steel	Wire material		Steel wire		Cold forgeability		Aging heat treatment		Bolt product		Remarks
			Wire diameter (mm)	Tensile strength (N/mm ²)	Red. (%)	Tensile strength (N/mm ²)	Work cracking	Tool life	Temperature (°C)	Time (min.)	Tensile strength (N/mm ²)	Corrosion resistance	
Example of the present invention	1	A	6	620	24.9	830	No	o	-	-	880	o	
	2								480	30	950	o	
	3								530	40	930	o	
	4	B	6	700	24.9	870	No	o	-	-	940	o	
	5	C	5.5	730	10.6	800	No	o	-	-	830	o	
	6	D	6.5	550	36.0	850	No	o	-	-	900	o	
	7	E	6	650	24.9	840	No	o	-	-	880	o	
	8	F	6	670	24.9	860	No	o	-	-	880	o	
	9	G	6	650	24.9	850	No	o	-	-	880	o	
	10	H	6	650	24.9	850	No	o	-	-	870	o	
	11	I	6	690	24.9	900	No	o	-	-	920	o	
	12	J	5.5	690	10.6	800	No	o	-	-	850	o	
	13	K	6	630	24.9	820	No	o	-	-	830	o	
	14	L	6	590	24.9	830	No	o	-	-	850	o	
	15	M	6	620	24.9	810	No	o	-	-	840	o	
	16	N	6.5	620	36.0	880	No	o	-	-	900	o	
	17		6.5						300	90	1000	o	
	18		6.5						450	60	1050	o	
*													

* not within the claims

Table 6

Category	No.	Steel	Wire material		Steel wire		Cold forgeability		Aging heat treatment		Bolt product		Remarks
			Wire diameter (mm)	Tensile strength (N/mm ²)	Red. (%)	Tensile strength (N/mm ²)	Work cracking	Tool life	Temperature (°C)	Time (min.)	Tensile strength (N/mm ²)	Corrosion resistance	
*	19	O	6.5	630	36.0	900	No	o	-	-	950	o	
	20		6.5						450	60	1120	o	
	21		6.5						550	5	1000	o	
Example of the present invention	22	P	6	650	24.9	850	No	o	-	-	870	o	
	23	Q	5.5	680	10.6	820	No	o	-	-	850	o	
	24	R	5.5	660	10.6	800	No	o	-	-	820	o	
	25	s	6	650	24.9	840	No	o	-	-	880	o	
	26	T	5.5	680	10.6	810	No	o	-	-	830	o	
	27	U	5.5	670	10.6	820	No	o	-	-	840	o	
	28	V	6	660	24.9	900	No	o	-	-	920	o	
	29	W	5.5	680	10.6	800	No	o	-	-	830	o	
	30	X	6	630	24.9	820	No	o	-	-	850	o	
	31	Y	6	640	24.9	830	No	o	-	-	850	o	
	32	Z	6	640	24.9	840	No	o	-	-	870	o	
	33	AA	6	630	24.9	830	No	o	-	-	870	o	
	34	BBB	6	630	24.9	850	No	o	-	-	860	o	
	35	CCC	6	640	24.9	840	No	o	-	-	850	o	
	36	DDD	6	650	24.9	860	No	o	-	-	870	o	
	37	EEE	6	650	24.9	860	No	o	-	-	870	o	

* not within the claims

Table 7

No.	Steel	Wire material		Steel wire		Cold forgeability		Aging heat treatment		Bolt product		Remarks
		Wire diameter (mm)	Tensile strength (N/mm ²)	Red. (%)	Tensile strength (N/mm ²)	Work cracking	Tool life	Temperature (°C)	Time (min.)	Tensile strength (N/mm ²)	Corrosion resistance	
38	N	6.5	620	36.0	900	No	o	650	30	690	o	
39		6.5	620	36.0	900	No	o	550	200	670	o	
40	AB	5.5	760	10.6	910	Yes	x	-	-	980	x	
41	AC	5.5	760	10.6	950	Yes	x	-	-	1000	o	
42	AD	6	680	24.9	900	No	x	-	-	950	o	
43	AE	6	770	24.9	950	Yes	x	-	-	1000	x	
44	AF	6	700	24.9	900	Yes	x	-	-	1050	o	
45	AG	6	530	24.9	650	No	o	-	-	680	o	
46	AH	6	770	24.9	950	Yes	x	-	-	970	o	High cost
47	AI	6	760	24.9	900	No	x	-	-	950	o	High cost
48	AJ	6	780	24.9	1010	Yes	x	-	-	1050	x	
49	AK	5.5	580	10.6	630	No	o	-	-	680	o	

* Underlines indicate values or results outside of the ranges specified by the present invention.

Table 8

No.	Steel	Wire material		Steel wire		Cold forgeability		Aging heat treatment		Bolt product		Remarks
		Wire diameter (mm)	Tensile strength (N/mm ²)	Red. (%)	Tensile strength (N/mm ²)	Work cracking	Tool life	Temperature (°C)	Time (min.)	Tensile strength (N/mm ²)	Corrosion resistance	
50	AL	6	-	-	-	-	-	-	-	-	-	Cannot be produced by hot processes
51	AM	6	<u>760</u>	24.9	900	No	×	-	-	960	○	
52	AN	5.5	680	10.6	830	<u>Yes</u>	○	-	-	850	×	
53	AO	5.5	650	10.6	820	<u>Yes</u>	○	-	-	860	○	
54	AP	5.5	680	10.6	830	<u>Yes</u>	○	-	-	880	○	
55	AQ	5.5	670	10.6	840	<u>Yes</u>	○	-	-	880	○	
56	AR	5.5	690	10.6	830	<u>Yes</u>	○	-	-	890	○	
57	AS	5.5	680	10.6	830	<u>Yes</u>	○	-	-	870	○	
58	AT	5.5	680	10.6	840	<u>Yes</u>	○	-	-	890	○	
59	AU	5.5	670	10.6	840	<u>Yes</u>	○	-	-	890	○	
60	AV	6	670	24.9	850	<u>Yes</u>	×	-	-	900	○	
61	AW	6	620	24.9	850	No	×	-	-	920	○	High cost

* Underlines indicate values or results outside of the ranges specified by the present invention.

[0079] Mechanical properties were evaluated by using the tensile test method prescribed in JIS Z 2241 to evaluate the tensile strength and the reduction of area at fracture. The steel wires of the examples of the present invention were all within a range from 650 to 1,000 N/mm², and the bolt products of the examples of the present invention were all within a range from 700 to 1,000 N/mm², indicating a high level of strength.

[0080] To determine the volume fraction of the ferrite phase of the steel wire, a cross-sectional surface of the steel wire was polished to a mirror finish, the ferrite phase was stained using Murakami's reagent, and image analysis was used to calculate the area ratio. The ferrite fraction in the steel wire of the examples of the present invention was within a range from 45% to 85% by volume.

[0081] The cold forgeability was evaluated by using three-stage heading equipment to form 5000 hexagonal heads, and checking for the presence of cracking or tool damage. A symbol O was recorded in the tool life column if no tool damage occurred, and a symbol × was recorded if tool damage occurred. With the steel wire of the examples of the present invention, no cold cracking was observed and the tool life was evaluated using the symbol O, indicating excellent cold forgeability.

[0082] The corrosion resistance of the bolt product was evaluated by subjecting 10 units of each bolt product to the salt spray test prescribed in JIS Z 2371 for 100 hours, and determining whether or not rusting occurred. If rust was absent, or present only in the form of minor rust spots, a symbol O was recorded in the corrosion resistance column. If outflow rust was present or rust appeared over the entire surface, a symbol x was recorded in the corrosion resistance column. The bolt products of the examples of the present invention all achieved an evaluation of O for the corrosion resistance.

[0083] On the other hand, comparative examples 38 to 61, which were outside the scope of the present invention, were inferior in terms of properties such as the cold forgeability, bolt product strength and/or corrosion resistance, clearly demonstrating the superiority of the present invention.

EXAMPLE 2 (not within the claims)

[0084] Table 9 and Table 10 show the chemical composition (in terms of mass %) of the steels (sample materials) used in example 2.

Table 9

Steel	C	Si	Mn	P	S	Ni	Cr	Cu	Mo	Al	O	N	Other	C+N	M value
AX	0.01	0.5	2.0	0.025	0.001	5.1	23.5	0.1	-	-	0.006	0.01	-	0.02	48.2
AY	0.04	0.6	2.1	0.016	0.002	4.1	22.9	0.05	-	-	0.006	0.04	-	0.08	57.4
AZ	0.02	0.9	2.0	0.025	0.001	4.3	23.5	0.3	-	-	0.005	0.03	-	0.05	48.1
BA	0.02	0.6	9.7	0.024	0.001	1.9	24.0	0.4	-	-	0.005	0.03	-	0.05	48.3
BB	0.01	0.5	1.1	0.032	0.003	5.8	23.4	0.3	-	-	0.006	0.02	-	0.03	26.2
BC	0.03	0.8	5.5	0.018	0.001	5.2	18.9	0.2	-	-	0.005	0.03	-	0.06	55.8
BD	0.03	0.4	5.5	0.019	0.002	5.1	25.5	0.2	-	-	0.005	0.02	-	0.05	-23.4
BE	0.02	0.5	2.1	0.025	0.001	3.6	23.4	0.8	-	-	0.006	0.03	-	0.05	58.1
BF	0.01	0.4	1.9	0.028	0.002	3.5	23.2	2.5	-	-	0.007	0.01	-	0.02	30.9
BG	0.02	0.5	3.5	0.032	0.001	3.8	22.7	0.3	0.8	-	0.005	0.03	-	0.05	50.3
BH	0.02	0.4	3.5	0.022	0.002	3.8	22.5	0.3	2.3	-	0.005	0.02	-	0.04	30.8
BI	0.02	0.5	2.2	0.027	0.001	5.0	23.2	0.2	-	-	0.005	0.02	B; 0.005	0.04	41.5
BJ	0.02	0.5	2.3	0.028	0.001	5.1	23.3	0.2	-	0.035	0.003	0.01	-	0.03	41.0
BK	0.01	0.6	2.2	0.026	0.002	5.0	23.2	0.3	-	-	0.005	0.02	Mg; 0.003	0.03	42.3
BL	0.02	0.4	2.2	0.026	0.002	5.1	23.1	0.1	-	-	0.005	0.02	Ca; 0.005	0.04	43.8
BM	0.02	0.5	2.0	0.027	0.002	5.1	22.9	0.1	-	0.02	0.005	0.02	Ca; 0.003	0.04	47.2
BN	0.01	0.4	2.1	0.026	0.002	5.1	23.2	0.1	-	-	0.005	0.02	Nb; 0.4	0.03	47.8
BO	0.03	0.5	2.2	0.032	0.003	5.2	22.8	0.2	-	-	0.005	0.02	Ti; 0.3	0.05	36.5
BP	0.02	0.4	2.1	0.025	0.003	5.2	23.1	0.1	-	-	0.006	0.02	V; 0.6	0.04	41.7
BQ	0.03	0.6	1.8	0.023	0.003	5.3	22.8	0.2	-	-	0.006	0.01	Zr; 0.4	0.04	40.6
BR	0.02	0.6	1.7	0.023	0.003	5.2	23.0	0.3	-	-	0.005	0.01	Nb; 0.3, Ti; 0.1	0.03	43.3
FFF	0.02	0.4	1.9	0.031	0.004	4.3	23.5	0.2	0.2	-	0.006	0.03	B; 0.003	0.05	52.7
GGG	0.02	0.3	1.8	0.025	0.005	4.5	24	0.3	0.3	0.03	0.005	0.04	Ca; 0.002	0.06	32.4
HHH	0.04	0.4	1.8	0.028	0.004	4.5	24	0.2	0.1	-	0.007	0.04	Nb; 0.08	0.06	38.1

not within the claims

Table 10

Steel	C	Si	Mn	P	S	Ni	Cr	Cu	Mo	Al	O	N	Other	C+N	M value
BS	<u>0.06</u>	0.5	1.8	0.032	0.004	5.2	23.1	0.1			0.006	0.02		0.08	24.7
BT	0.02	0.6	2.2	0.027	0.003	5.6	23.1	0.3			0.005	0.07		0.09	-1.5
BU	0.05	0.4	1.9	0.028	0.003	5.5	23.3	0.2			0.005	0.05		<u>0.1</u>	1.2
BV	0.03	<u>1.5</u>	1.8	0.024	0.002	5.5	23.0	0.3			0.005	0.03		0.06	11.6
BW	0.03	0.6	<u>11.5</u>	0.032	0.004	5.3	22.8	0.2			0.007	0.02		0.05	-42.6
BX	0.03	0.6	9.8	0.028	0.004	<u>1.1</u>	23.3	0.2			0.006	0.03		0.06	<u>81.5</u>
BY	0.02	0.8	2.3	0.023	0.003	<u>7.3</u>	23.3	0.1			0.005	0.02		0.04	-27.3
BZ	0.02	0.8	6.8	0.023	0.003	5.6	17.3	0.3			0.005	0.02		0.04	<u>62.0</u>
CA	0.02	0.4	1.3	0.023	0.003	5.4	<u>30.3</u>	0.2			0.005	0.02		0.04	-59.2
CB	0.01	0.6	1.8	0.028	0.002	5.6	23.1	<u>3.2</u>			0.005	0.02		0.03	-54.6
CC	0.03	0.7	1.8	0.027	0.002	5.5	23.2	0.05	<u>3.1</u>		0.005	0.03		0.06	-33.9
CD	0.02	0.6	2.2	0.032	0.003	5.3	23.1	0.1			0.006	0.02	<u>B; 0.023</u>	0.04	36.1
CE	0.02	0.6	2.1	0.033	0.003	5.2	22.8	0.2		<u>0.15</u>	0.004	0.02		0.04	41.0
CF	0.02	0.6	2.2	0.032	0.004	5.4	22.8	0.3			0.005	0.01	<u>Mg; 0.015</u>	0.03	36.1
CG	0.02	0.5	1.9	0.03	0.003	5.5	23.1	0.3			0.005	0.03	<u>Ca; 0.018</u>	0.05	23.2
CH	0.02	0.5	2.1	0.032	0.002	5.4	23.1	0.4			0.005	0.02	<u>Nb; 1.3</u>	0.04	26.2
CI	0.02	0.6	2.2	0.033	0.003	5.5	23.2	0.3			0.004	0.02	<u>Ti; 0.8</u>	0.04	23.1
CJ	0.01	0.4	1.9	0.028	0.001	5.6	22.9	0.2			0.006	0.02	<u>V; 1.8</u>	0.03	36.1
CK	0.03	0.5	1.9	0.028	0.002	5.4	22.8	0.1			0.005	0.02	<u>Zr; 1.5</u>	0.05	36.1
CL	0.01	0.4	1.6	0.027	0.003	4.7	22.7	0.1			0.005	0.02		0.03	70.3
CM	0.05	0.5	1.7	0.028	0.004	5.4	22.8	0.1			0.006	0.05		<u>0.1</u>	14.6
CN	0.04	0.6	1.1	0.025	0.005	9.8	18.5	0.1	0.1		0.006	0.05		0.09	-47A

Comparative steel

* Underlines indicate values or results outside of the ranges specified by the present invention.

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[0085] Steels having these chemical compositions were each melted in a 150 kg vacuum melting furnace and cast into a $\varnothing 180$ mm steel slab. The steel slab was then subjected to a hot wire rod rolling process to a diameter of $\varnothing 5.5$ mm, and after completing hot rolling at 1050°C , the resulting product was maintained at 1050°C for 5 minutes, subjected to continuous water-cooled heat treatment, and then acid-washed to obtain a wire material. Thereafter, heavy cold drawing was performed by a standard process to a diameter of $\varnothing 2.0$ mm, and the resulting steel wire was subjected to bending by a cold process to obtain a wire netting mesh for use in a conveyor.

[0086] Evaluations were conducted by determining the tensile strength, the reduction of area at tensile fracture, the cold workability, the corrosion resistance, and the magnetizability of the wire material. The results of these evaluations are recorded in Table 11 and Table 12.

Table 11

Category	No.	Steel	Tensile strength (N/mm ²)	Reduction of area at tensile fracture (%)	Cold workability	Corrosion resistance	Magnetizability	Remarks
not within the claims	62	AX	540	83	○	○	Yes	
	63	AY	650	70	○	○	Yes	
	64	AZ	610	76	○	○	Yes	
	65	BA	650	79	○	○	Yes	
	66	BB	560	80	○	○	Yes	
	67	BC	650	80	○	○	Yes	
	68	BD	610	76	○	○	Yes	
	69	BE	530	81	○	○	Yes	
	70	BF	530	71	○	○	Yes	
	71	BG	590	79	○	○	Yes	
	72	BH	630	72	○	○	Yes	
	73	BI	600	75	○	○	Yes	
	74	BJ	610	76	○	○	Yes	
	75	BK	590	79	○	○	Yes	
	76	BL	570	75	○	○	Yes	
	77	BM	580	75	○	○	Yes	
	78	BN	640	71	○	○	Yes	
	79	BO	630	72	○	○	Yes	
	80	BP	640	75	○	○	Yes	
	81	BQ	650	76	○	○	Yes	
	82	BR	660	72	○	○	Yes	
	83	FEE	600	80	○	○	Yes	
	84	GGG	590	78	○	○	Yes	
	85	HHH	580	78	○	○	Yes	

Table 12

Category	No.	Steel	Tensile strength (N/mm ²)	Reduction of area at tensile fracture (%)	Cold workability	Corrosion resistance	Magnetizability	Remarks
Comparative example	86	BS	690	68	x	x	Yes	
	87	BT	710	66	x	o	Yes	
	88	BU	730	65	x	o	Yes	
	89	BV	680	70	x	o	Yes	
	90	BW	720	70	x	x	Yes	
	91	BX	660	72	x	o	Yes	
	92	BY	560	75	o	o	Yes	Poor economic viability
	93	BZ	650	70	x	x	Yes	
	94	CA	680	68	x	o	Yes	
	95	CB	-	-	-	-	Yes	Did not survive manufacturing process (fractured under heat)
	96	CC	720	65	x	o	Yes	
	97	CD	620	68	x	x	Yes	
	98	CE	610	72	x	o	Yes	
	99	CF	620	73	x	o	Yes	
	100	CG	610	72	x	o	Yes	
	101	CH	650	73	x	o	Yes	
	102	CI	640	72	x	o	Yes	
	103	CJ	650	73	x	o	Yes	
	104	CK	640	74	x	o	Yes	
	105	CL	720	73	x	o	Yes	
	106	CM	730	72	x	o	Yes	
	107	CN	620	78	o	o	No	High raw material costs due to expensive Ni

[0087] The tensile strength and reduction of area at tensile fracture for the wire materials were evaluated by using the tensile test method prescribed in JIS Z 2241 to evaluate the tensile strength and the reduction of area at fracture. The wire materials of examples No. 62 to 85 (which are not within the claims) all exhibited a tensile strength within the range from 500 to 700 N/mm², and a reduction of area at fracture of $\geq 70\%$.

[0088] The cold workability was evaluated in terms of the cold drawing process and subsequent wire workability. If an unbroken and unbent wire netting was produced, a symbol O was recorded in the cold forgeability column, and if the wire netting could not be formed due to wire breakage or bending or the like, a symbol x was recorded. The wire materials of examples No. 62 to 85 (which are not within the claims) exhibited no breakage or bending, and displayed excellent cold workability.

[0089] The corrosion resistance was evaluated by polishing the surface layer of the acid-washed wire material with a #500 sandpaper, and then performing the salt spray test prescribed in JIS Z 2371 for 100 hours and determining whether or not rusting occurred. If rust was absent, or present only in the form of minor rust spots, a symbol O was recorded in the corrosion resistance column. If outflow rust was present or rust appeared over the entire surface, a symbol x was recorded. The steels of Examples No. 62 to 85 (which are not within the claims) all achieved an evaluation of O for the corrosion resistance.

[0090] The magnetizability was determined by using a ferrite meter (a simple instrument for measuring magnetic permeability) to measure the relative magnetic permeability of the wire netting. If the wire netting had a relative magnetic permeability of 3.0 or higher, at which magnetizability is clearly demonstrable, the wire netting was adjudged to be magnetizable, whereas at less than 3.0, the wire mesh was adjudged non-magnetizable.

[0091] On the other hand, comparative examples 86 to 107, which are outside the scope of the present invention, were inferior in terms of properties such as the cold workability, corrosion resistance, cost, and magnetizability, clearly demonstrating the superiority of the present invention.

INDUSTRIAL APPLICABILITY

[0092] As is apparent from the examples described above, the highly corrosion resistant duplex stainless steel wire material of the present invention, which contains only a small amount of expensive Ni, provides excellent cold forgeability and the ability to increase the strength of a bolt product, thus enabling a high strength and highly corrosion resistant bolt to be provided at low cost, while also being applicable to nuts, and is therefore extremely useful in industrial terms.

[0093] As is also apparent from the examples described above, the present invention can also be used to manufacture a soft and magnetizable low-cost duplex stainless steel wire material, can impart excellent cold workability as well as corrosion resistance equivalent to austenite stainless steels such as SUS304 and SUS316, and is capable of providing magnetizable and highly corrosion resistant cold forged components such as screws, pins, wire netting, wire, rope and springs, and is therefore extremely useful in industrial terms.

Claims

1. An austenite-ferrite duplex steel wire having excellent cold forgeability for producing a high strength and highly corrosion resistant bolt, the steel wire consisting of in term of mass %,
 - C: 0.005 to 0.05%,
 - Si: 0.1 to 1.0%,
 - Mn: 0.1 to 10.0%,
 - Ni: 1.0 to 6.0%,
 - Cr: 19.0 to 30.0%,
 - Cu: not less than 0.2 %, but less than 1.0 %,
 - N: 0.005 to 0.20%,
 - optionally one or more selected from Mo: not more than 1.0%, B: not more than 0.01%, Al: not more than 0.1%, Mg: not more than 0.01%, and Ca: not more than 0.01%, Nb: not more than 1.0%, Ti: not more than 0.5%, V: not more than 1.0%, and Zr: not more than 1.0% with a remainder being iron and unavoidable impurities,
 - wherein C+N is not more than 0.20%, an M value represented by formula (a) is not more than 60, an F value represented by formula (b) is from 45 to 85,
 - and a tensile strength is within a range from 700 to 1000 N/mm²,

$$M = 551 - 462(C+N) - 9.2Si - 8.1Mn - 29(Ni+Cu) - 13.7Cr - 18.5Mo \quad (a)$$

$$F = 5.6Cr - 7.1Ni + 2.4Mo + 15Si - 3.1Mn - 300C - 134N - 26.6 \quad (b)$$

2. A high strength and highly corrosion resistant bolt, the bolt having a chemical composition described in claim 1, and a tensile strength within a range from 700 to 1,200 N/mm².
3. A method of manufacturing a high strength and highly corrosion resistant bolt, the method comprising: subjecting an austenite-ferrite duplex steel wire having a chemical composition described in claim 1 and having a tensile strength within a range from 700 to 1,000 N/mm² to cold bolt forming, and subsequently performing an aging heat treatment at 300 to 600°C for 1 to 100 minutes.

Patentansprüche

1. Ein Austenit-Ferrit-Duplexstahldraht mit hervorragender Kaltschmiedbarkeit zur Herstellung eines hochfesten und hochkorrosionsbeständigen Bolzens, wobei der Stahldraht, bezogen auf Massen-%, besteht aus:

C: 0,005 bis 0,05%,
 Si: 0,1 bis 1,0%,
 Mn: 0,1 bis 10,0%,
 Ni: 1,0 bis 6,0%,
 Cr: 19,0 bis 30,0%,
 Cu: nicht weniger als 0,2 % aber weniger als 1,0 %,
 N: 0,005 bis 0,20%,

gegebenenfalls einem oder mehreren, ausgewählt aus Mo: nicht mehr als 1,0%, B: nicht mehr als 0,01%, Al: nicht mehr als 0,1%, Mg: nicht mehr als 0,01% und Ca: nicht mehr als 0,01%, Nb: nicht mehr als 1,0%, Ti: nicht mehr als 0,5%, V: nicht mehr als 1,0% und Zr: nicht mehr als 1,0% mit einem Rest aus Eisen und unvermeidbaren Verunreinigungen,

wobei C+N nicht mehr als 0,20% beträgt, ein M-Wert dargestellt durch Formel (a) nicht mehr als 60 beträgt, ein F-Wert dargestellt durch Formel (b) 45 bis 85 beträgt, und eine Zugfestigkeit innerhalb eines Bereichs von 700 bis 1000 N/mm² liegt,

$$M = 551 - 462(C+N) - 9,2Si - 8,1Mn - 29(Ni+Cu) - 13,7Cr - 18,5Mo \quad (a)$$

$$F = 5,6Cr - 7,1Ni + 2,4Mo + 15Si - 3,1Mn - 300C - 134N - 26,6 \quad (b)$$

2. Ein hochfester und hochkorrosionsbeständiger Bolzen, wobei der Bolzen eine chemische Zusammensetzung wie in Anspruch 1 beschrieben und eine Zugfestigkeit innerhalb eines Bereichs von 700 bis 1200 N/mm² aufweist.
3. Ein Verfahren zur Herstellung eines hochfesten und hochkorrosionsbeständigen Bolzens, wobei das Verfahren umfasst:
 Unterziehen eines Austenit-Ferrit-Duplexstahldrahts mit einer chemischen Zusammensetzung wie in Anspruch 1 beschrieben und einer Zugfestigkeit innerhalb eines Bereichs von 700 bis 1000 N/mm² einem Kaltbolzenformen und anschließendes Durchführen einer Alterungswärmebehandlung bei 300 bis 600°C für 1 bis 100 Minuten.

Revendications

1. Fil en acier duplex austénite-ferrite ayant une excellente forgeabilité à froid pour produire un boulon ayant une résistance mécanique élevée et une résistance à la corrosion élevée, le fil d'acier étant constitué, en termes de pourcentages en masse, de
 C : 0,005 à 0,05 %,
 Si : 0,1 à 1,0 %,
 Mn : 0,1 à 10,0 %,

Ni : 1,0 à 6,0 %,
 Cr : 19,0 à 30,0 %,
 Cu : au moins 0,2 %, mais moins de 1,0 %,
 N : 0,005 à 0,20 %,

éventuellement un ou plusieurs choisis parmi Mo : au plus 1,0 %, B : au plus 0,01 %, Al : au plus 0,1 %, Mg : au plus 0,01 %, et Ca : au plus 0,01 %, Nb : au plus 1,0 %, Ti : au plus 0,5 %, V : au plus 1,0 %, et Zr : au plus 1,0 %, le reste étant du fer et des impuretés inévitables, dans lequel C+N ne vaut pas plus de 0,20 %, la valeur M représentée par la formule (a) ne vaut pas plus de 60, la valeur F représentée par la formule (b) vaut de 45 à 85, et la résistance à la traction est située dans la plage allant de 700 à 1 000 N/mm²,

$$M = 551 - 462(C+N) - 9,2Si - 8,1Mn - 29(Ni+Cu) - 13,7Cr - 18,5Mo \quad (a)$$

$$F = 5,6Cr - 7,1Ni + 2,4Mo + 15Si - 3,1Mn - 300C - 134N - 26,6 \quad (b)$$

2. Boulon ayant une résistance mécanique élevée et une résistance à la corrosion élevée, le boulon ayant une composition chimique décrite dans la revendication 1, et une résistance à la traction située dans la plage allant de 700 à 1 200 N/mm².
3. Méthode de fabrication d'un boulon ayant une résistance mécanique élevée et une résistance à la corrosion élevée, la méthode comprenant :
 la soumission d'un fil en acier duplex austénite-ferrite ayant une composition chimique décrite dans la revendication 1 et ayant une résistance à la traction située dans la plage allant de 700 à 1 000 N/m² à une formation de boulon à froid, et ensuite la mise en œuvre d'un traitement de vieillissement à la chaleur à une température de 300 à 600 °C pendant 1 à 100 minutes.

FIG. 1

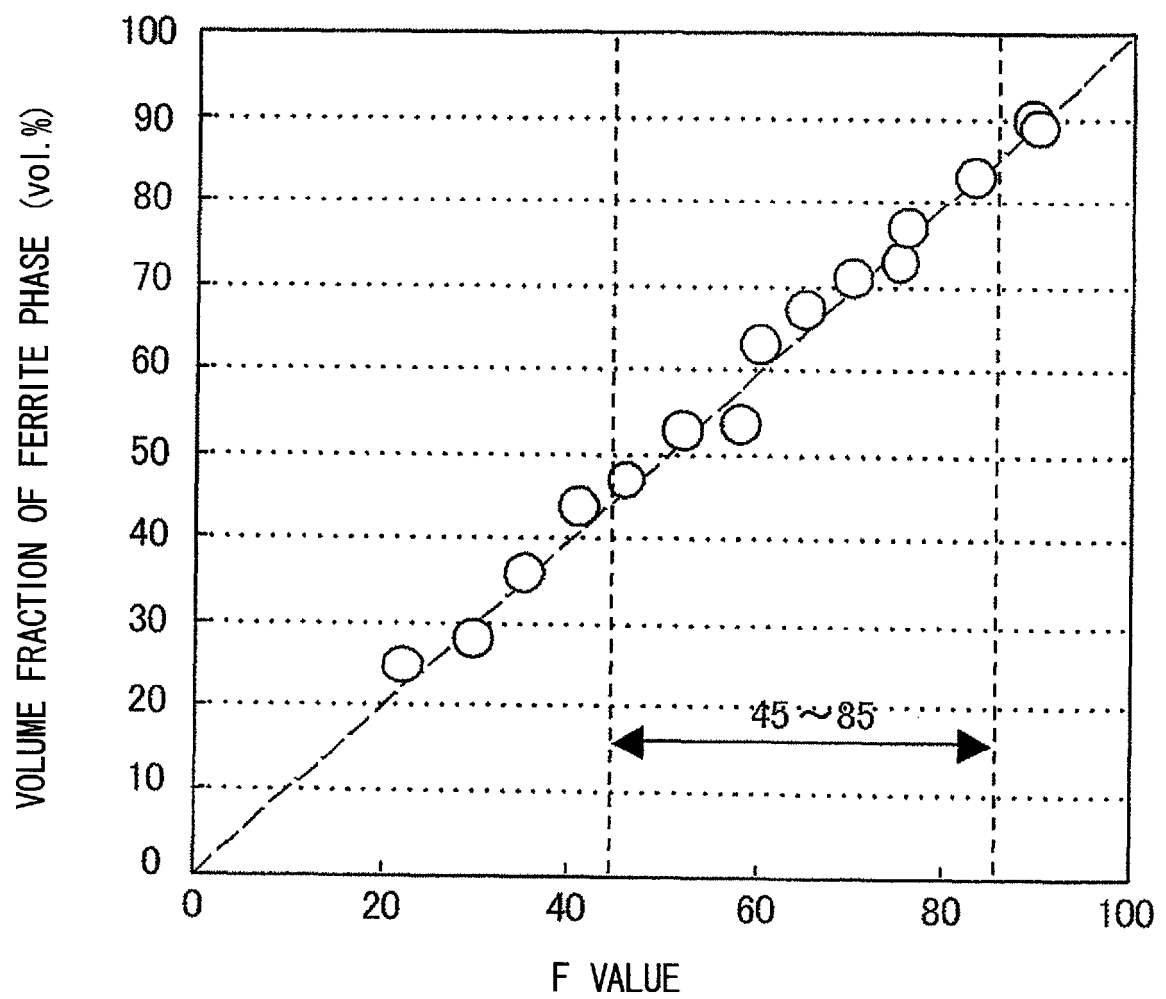
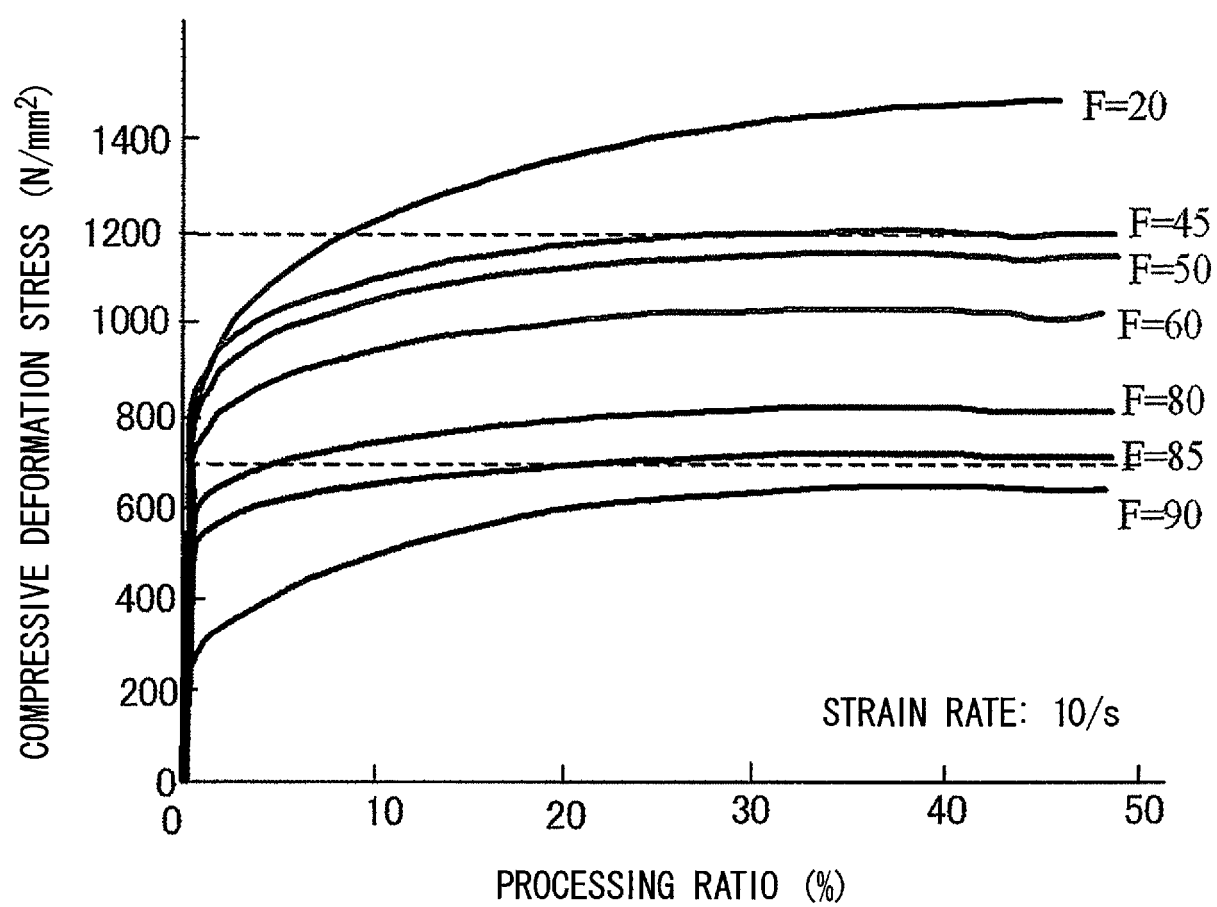


FIG. 2



REFERENCES CITED IN THE DESCRIPTION

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