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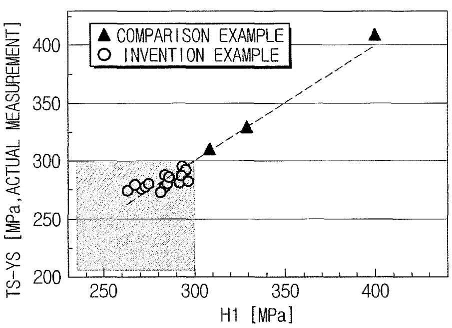
(54) AUSTENITIC STAINLESS STEEL HAVING EXCELLENT FLEXIBILITY

(57) Austenitic stainless steels excellent in flexibility are disclosed. The austenitic stainless steel excellent in flexibility according to the present invention is characterized by comprising, by weight percent, 0.1 to 0.65% of Si, 1.0 to 3.0% of Mn, 6.5 to 10.0% of Ni, 16.5 to 18.5% of Cr, 6.0% or less of Cu (excluding 0), 0.13% or less of (C + N) (excluding 0), and the remainder comprising Fe and unavoidable impurities, wherein the work hardening formula H1 defined by the following formula is 300 or less.

$$H1 = -459 + 79.8Si - 10.2Mn - 8.16Ni + 48.0Cr - 13.2Cu + 623(C+N)$$

【Fig. 1】



EP 3 239 341 A1

Description

[Technical Field]

[0001] The present invention relates to austenitic stainless steels excellent in flexibility.

[Background Art]

[0002] Attempts have been made to apply stainless steel to air conditioner refrigerant piping for conventional household use and automobiles. This is because it is not only excellent in corrosion resistance but also relatively low in material cost.

[0003] However, work such as bending of piping is essential since installation of air conditioner refrigerant piping is limited by the installation space, but there exists a problem in that the general stainless steel does not have the flexibility that must be provided in piping installation.

[0004] A metal material has a property that when subjected to strain such as tensile or compression, work hardening occurs and it becomes stronger as it is subjected to strain. The bending of pipe is a complex action of tension and compression, and as the degree of bending increases, the material becomes more hardened. In particular, SUS 304, which is most widely used as austenitic stainless steel, has a severe degree of work hardening, and it is very difficult to bend piping by manpower in a space where air conditioner piping work is required.

[0005] Work hardening is expressed as TS-YS, which is the difference between the yield strength (YS) indicating the strength at the start of material deformation and the tensile strength (TS) indicating the maximum strength due to maximization of work hardening of the material. In other words, in order to bend the material easily with manpower, a material in which TS-YS is minimized by suppressing such work hardening phenomenon is required.

[0006] In the austenitic stainless steels, Cr, Ni, Mn, Cu, C and N elements are mainly added. Although many steel types have been produced by varying the content of these elements, an optimum component control method for excellent flexibility has not been disclosed. In the present invention, it was attempted to produce materials having excellent flexibility by minimizing work hardening through control of these elements.

[0007] It should be understood that the foregoing description of the background art is merely for the purpose of promoting an understanding of the background of the present invention, and is not to be construed as admission that it is the prior art known to those skilled in the art.

(Patent Literature 0001) KR 10-2010-0099726 A (2010.09.13)

[Disclosure of Invention]

[Technical Problem]

[0008] An object of the present invention is to provide austenitic stainless steels excellent in flexibility by controlling the content of component elements affecting the degree of work hardening and controlling the size of crystal grains in order to solve such conventional problems.

[Technical Solution]

[0009] To achieve the object described above, an austenitic stainless steel excellent in flexibility according to the present invention is characterized by comprising, by weight percent, 0.1 to 0.65% of Si, 1.0 to 3.0% of Mn, 6.5 to 10.0% of Ni, 16.5 to 18.5% of Cr, 6.0% or less ot Cu (excluding 0), 0.13% or less of (C + N) (excluding 0), and the remainder comprising Fe and unavoidable impurities, wherein the work hardening formula H1 defined by the following formula is 300 or less.

$$H1 = -459 + 79.8Si - 10.2Mn - 8.16Ni + 48.0Cr - 13.2Cu + 623(C+N)$$

[0010] The austenitic stainless steel excellent in flexibility according to the present invention is characterized by having the size of structure (D) of 20 to 40μm.

[0011] To achieve the object described above, an austenitic stainless steel excellent in flexibility according to the present invention is characterized by comprising, by weight percent, 0.1 to 0.65% of Si, 1.0 to 3.0% of Mn, 6.5 to 10.0% of Ni, 16.5 to 18.5% of Cr, 6.0% or less of Cu (excluding 0), 0.13% or less of (C + N) (excluding 0), and the remainder comprising Fe and unavoidable impurities, wherein the work hardening formula H2 defined by the following formula is 300 or less.

$$H2 = 4.27 + 0.875(-459 + 79.8Si - 10.2Mn - 8.16Ni + 48.0Cr - 13.2Cu + 623(C+N)) - 287D \text{ (D: the size of structure)}$$

[0012] The size of structure (D) is characterized by being 20 to 300μm.

[0013] An austenitic stainless steel excellent in flexibility according to the present invention is characterized by comprising, by weight percent, 0.1 to 0.65% of Si, 1.0 to 3.0% of Mn, 6.5 to 10.0% of Ni, 16.5 to 18.5% of Cr, 6.0% or less of Cu (excluding 0), 0.13% or less of (C + N) (excluding 0), and the remainder comprising Fe and unavoidable impurities, wherein M_{d30} defined by the following formula is 0 or less.

$$M_{d30} = 551 - 462(C+N) - 9.2Si - 8.1Mn - 29(Ni+Cu) - 13.7Cr$$

[0014] It is preferable that M_{d30} is -100 to 0.

[0015] The difference value between TS (tensile strength) and YS (yield strength) is characterized by being 300MPa or less.

[Advantageous Effects]

[0016] The present invention has an advantage that austenitic stainless steels excellent in flexibility can be produced by controlling the content of elements, the size of crystal grains, and the like.

[Brief Description of Drawings]

[0017]

FIG. 1 is a diagram showing a correlation between the work hardening formula H1 and actually measured values of work hardening degree;

FIG. 2 is a diagram showing a change of the work hardening formula H1 according to the size of crystal grains;

FIGS. 3 to 5 show size distributions of crystal grains;

FIG. 6 is a diagram showing a correlation between the modified work hardening formula H2 and actually measured values of the work hardening degree; and

FIG. 7 is a diagram showing a correlation between the austenite stabilization index and actually measured values of the work hardening degree.

[Mode for Invention]

[0018] Hereinafter, austenitic stainless steels excellent in flexibility according to preferred embodiments of the present invention will be described with reference to the accompanying drawings.

[0019] An austenitic stainless steel according to the present invention is characterized by containing, by weight percent, 0.1 to 0.65% of Si, 1.0 to 3.0% of Mn, 6.5 to 10.0% of Ni, 16.5 to 18.5% of Cr, 6.0% or less of Cu (excluding 0), 0.13% or less of (C + N) (excluding 0), and the remainder comprising Fe and unavoidable impurities.

[0020] The reasons for limiting the numerical values of the components constituting the austenitic stainless steel excellent in flexibility of the present invention will be described below.

[0021] C + N should be added to 0.13wt% or less.

[0022] C and N not only harden the austenitic stainless steel as interstitial solid solution strengthening elements but also increase the work hardening degree of the material by hardening the strain induced martensite generated during processing if the contents of C and N are high. Therefore, there is a need to limit the content of C and N, and in the present invention, the content of C + N is limited to 0.13% or less.

[0023] Si is added in a controlled amount with the range of 0.1 to 0.65wt%.

[0024] Since Si is an element added essentially for deoxidation, 0.1% or more is added.

[0025] However, when an excessively high content of Si is added, the material is hardened and the corrosion resistance is lowered by forming inclusions in association with oxygen, so the upper limit is limited to 0.65%.

[0026] Mn is added in a controlled amount with the range of 1.0 to 3.0wt%.

[0027] Mn, which is an element not only added essentially for deoxidation but also increases the degree of stabilization of the austenite phase, is added at 1.0% or more for maintaining the austenite balance. However, the addition of an excessively high content of Mn reduces the corrosion resistance of the material, so the upper limit is limited to 3.0%.

[0028] Ni is added in a controlled amount with the range of 6.5 to 10.0wt%.

[0029] Ni is not only effective for improving the corrosion resistance such as pitting corrosion resistance by being added with Cr in combination, but also can increase softening of austenite steel when its content is increased.

[0030] In addition, Ni is an element contributing to improvement of phase stability of austenitic stainless steel, and is added at 6.5% or more in order to maintain an austenite balance. However, the addition of an excessively high content of Ni results in an increase in the cost of the steel, so the upper limit is limited to 10.0%.

[0031] Cr is added in a controlled amount with the range of 16.5 to 18.5wt%.

[0032] Cr is an indispensable element for improving the corrosion resistance, and in order to be used for general purpose, 16.5% or more of Cr should be added. However, the addition of an excessively high content of Cr causes austenite phase hardening and increases the cost, so the upper limit is limited to 18.5%.

[0033] Cu is added in a controlled amount with the range of 6.0wt% or less.

[0034] Cu can cause softening of the austenite steel. However, the addition of an excessively high content of Cu lowers the hot workability and can rather harden the austenite phase, so the upper limit is limited to 6.0%.

[0035] In order to attain the object of the present invention, the component control method provided by the present invention is important. In order to express this specifically, the hollowing description will be made with reference to the embodiments of the present invention. The materials described in the following embodiments were prepared by preparing ingots with a 150 mm thickness, heating them to 1,250°C, hot rolling them to 3 mm, and then heat treating them at 1,100°C for 60 seconds or more. However, such a manufacturing method does not limit the characteristics of the material provided in the present invention, but merely adopts one of the conventional methods of manufacturing austenitic stainless steel, and is merely an example of producing a material for evaluating characteristics. The characteristics of the material change depending on the component control method provided by the present invention. The yield strength YS and the tensile strength TS are values obtained by uniaxially tensioning the material.

[Table 1]

Classification	Si	Mn	Ni	Cr	Cu	C+N	TS-YS	H1
Invention Example 1	0.4	2.7	8.0	17.3	2.7	0.019	281	292
Invention Example 2	0.4	1.7	9.6	17.4	3.2	0.028	277	284
Invention Example 3	0.4	1.7	9.6	17.4	3.2	0.024	273	281
Invention Example 4	0.4	2.8	9.6	17.5	3.1	0.010	276	271
Invention Example 5	0.4	2.7	9.6	17.4	3.2	0.011	279	267
Invention Example 6	0.4	2.7	9.7	17.5	3.2	0.019	277	273
Invention Example 7	0.4	2.7	9.6	17.4	3.2	0.041	280	285
Invention Example 8	0.4	1.2	8.3	16.9	2.1	0.016	287	286
Invention Example 9	0.4	1.2	8.4	16.9	2.2	0.033	295	294
Invention Example 10	0.4	1.2	8.1	17.0	2.8	0.018	288	284
Invention Example 11	0.4	1.2	8.0	17.0	2.7	0.036	293	295
Invention Example 12	0.4	1.2	8.4	16.8	2.7	0.017	280	275
Invention Example 13	0.4	1.2	8.4	17.0	2.7	0.036	287	293
Invention Example 14	0.6	1.2	7.6	16.9	3.0	0.017	283	296
Invention Example 15	0.6	1.2	7.6	16.9	4.0	0.021	286	286
Invention Example 16	0.6	1.2	7.6	16.7	5.0	0.020	274	263
Comparative Example 1	0.6	1.2	7.6	16.9	2.1	0.056	328	329
Comparative Example 2	0.4	1.0	7.9	17.7	0.2	0.088	407	399
Comparative Example 3	0.6	1.2	7.5	16.8	2.0	0.021	309	308

[0036] H1 shown in Table 1 is defined by the following formula.

$$H1 = -459 + 79.8Si - 10.2Mn - 8.16Ni + 48.0Cr - 13.2Cu + 623(C+N)$$

[0037] In the present invention, in order to obtain an austenitic stainless steel excellent in flexibility by controlling the TS-YS value to 300MPa or less, the H1 values are defined using the component elements constituting the present invention, and the correlation between the H1 values and the actually measured TS-YS values were analyzed.

[0038] As shown in FIG. 1, it can be seen that the relationship between the H1 values obtained through the component control and the actually measured TS-YS values is shown, and the above description is implemented. In particular, as shown by a dotted line, a linearly smooth relationship is established therebetween. Therefore, it can be seen that even if the lower limit of the H1 value is not set in the present invention, it is possible to manufacture an austenitic steel having more excellent flexibility through production of a material having a lower H1 value.

[0039] On the other hand, the crystal grain size of the austenitic stainless steel produced by a conventional manufacturing process is generally 30 $\pm$ 10μm.

[0040] As shown in Table 2, the crystal grain size (D) of the austenitic stainless steel excellent in flexibility of the present invention is also present in the interval of 30 $\pm$ 10 μm, and it can be seen that when H1 is obtained as 329 as in Comparative Example 1 of Table 2, the actual TS-YS value is obtained as 328, indicating that the flexibility is not good.

[0041] As above, it can be seen that the values of H1 and the actual TS-YS values have similar values at crystal grain sizes of the range of 30 $\pm$ 10μm, which is also confirmed through FIG. 2.

[0042] However, in a case when the size of the crystal grains exceeds the range of 30 $\pm$ 10μm, it can be seen that the actual TS-YS values are less than 300MPa even if the values of H1 exceed 300MPa, which is also confirmed through Invention Examples 17, 18, 19, 20 and 21 in Table 2 and the section marked as ellipse in FIG. 2.

[0043] If the crystal grain size is large, surface irregularity defect called orange peel occurs during processing. However, if the smoothness of the surface is not important or can be corrected through polishing and can be ignored, even if the crystal grain size is large, it is not a big problem.

[0044] FIGS. 3 to 5 show size distributions of crystal grains, in which FIG. 3 is a structure photograph showing the crystal grain size of the austenitic stainless steel according to the following Invention Example 6, FIG. 4 is a structure photograph showing the crystal grain size of the austenitic stainless steel according to the following Comparative Example 6, and FIG. 5 is a structure photograph showing the crystal grain size of the austenitic stainless steel according to the following Invention Example 17.

[0045] In the present invention, a modified work hardening formula H2 is provided so as to obtain a material having a low work hardening degree even when the crystal grain size is larger than usual.

$$H2 = 4.27 + 0.875H1 - 0.287D$$

[0046] As shown in Table 2 and FIG. 6, it can be seen that austenitic stainless steels excellent in flexibility can be produced by controlling the range of the modified work hardening formula H2 to 300MPa or less.

[Table 2]

	TS-YS	H1	D	H2
Invention Example 1	281	292	29	289
Invention Example 2	277	284	31	282
Invention Example 3	273	281	33	279
Invention Example 4	276	271	29	271
Invention Example 5	279	167	31	268
Invention Example 6	277	173	32	272
Invention Example 7	280	285	35	282
Invention Example 17	269	336	223	273
Invention Example 18	247	316	218	256
Invention Example 19	240	301	209	246
Invention Example 20	267	333	284	253
Invention Example 21	283	316	93	292

(continued)

	TS-YS	H1	D	H2
Comparative Example 1	328	329	33	321
Comparative Example 4	337	406	210	337
Comparative Example 5	371	406	990	372
Comparative Example 6	313	336	72	316

[0047] Table 3 shows the component contents of Invention Examples 17 to 21 and Comparative Examples 4 to 6 disclosed in Table 2.

[Table 3]

Classification	Si	Mn	Ni	Cr	Cu	C+N
Invention Example 17	0.6	1.2	7.5	16.7	3.9	0.119
Invention Example 18	0.6	1.3	7.6	17.0	5.0	0.087
Invention Example 19	0.6	1.3	7.9	17.1	5.8	0.075
Invention Example 20	0.5	1.1	6.9	17.1	4.4	0.091
Invention Example 21	0.6	1.3	7.6	17.0	5.0	0.087
Comparative Example 4	0.2	1.4	8.1	18.1	0.2	0.105
Comparative Example 5	0.2	1.4	8.1	18.1	0.2	0.105
Comparative Example 6	0.6	1.2	7.5	16.7	3.9	0.119

[0048] On the other hand, the TS-YS values may be limited by the following austenite stability M_{d30}.

[0049] As shown in FIG. 7, it can be seen that when M_{d30} exceeds 0, the TS-YS values greatly increase, and in the range where M_{d30} is 0 or less, the TS-YS values do not react sensitively to M_{d30} but remain at a constant low level.

[0050] In order to maintain the M_{d30} in the range of 0 or less, Si, Mn, Ni, Cu and Cr which are the main additive elements must be added. In the present invention, M_{d30}-related component parameters for maintaining the TS-YS values at 300MPa or less are presented.

[Table 4]

	TS-YS	M_{d30}
Invention Example 1	281	-30
Invention Example 2	227	88
Invention Example 3	273	85
Invention Example 4	276	88
Invention Example 5	279	88
Invention Example 6	277	-97
Invention Example 7	280	-102
Invention Examples 8	287	-2
Invention Example 9	295	-14
Invention Example 10	288	-18
Invention Example 11	293	-22
Invention Example 12	280	-21
Invention Example 13	287	-34

(continued)

	TS-YS	M_{d30}
Invention Example 14	283	-13
Invention Example 15	286	-41
Invention Example 16	274	-69
Comparative Example 1	328	-1
Comparative Example 2	407	20
Comparative Example 3	309	20

[0051] As shown in Table 4, when the values are maintained at 0 or less, the TS-YS values can be maintained at 300MPa or less, which indicates that the flexibility is improved.

[0052] On the other hand, in order to lower the M_{d30} values, the component element contents should be further increased. In order to reduce the cost, the lower limit value is preferably limited to -100.

[0053] While the present invention has been particularly shown and described with reference to specific embodiments thereof, it will be understood by those skilled in the art that the present invention may be variously modified and changed without departing from the technical idea of the present invention provided by the following claims.

[Industrial Applicability]

[0054] The austenitic stainless steels excellent in flexibility according to the embodiments of the present invention are applicable to air conditioner refrigerant piping and the like for domestic use and automobiles.

Claims

1. An austenitic stainless steel excellent in flexibility being **characterized by** comprising:

   by weight percent, 0.1 to 0.65% of Si, 1.0 to 3.0% of Mn, 6.5 to 10.0% of Ni, 16.5 to 18.5% of Cr, 6.0% or less of Cu (excluding 0), 0.13% or less of (C + N) (excluding 0), and the remainder comprising Fe and unavoidable impurities,
   wherein the work hardening formula H1 defined by the following formula is 300 or less.

$$H1 = -459 + 79.8Si - 10.2Mn - 8.16Ni + 48.0Cr - 13.2Cu + 623(C+N)$$

2. The austenitic stainless steel excellent in flexibility according to claim 1, being **characterized by** having the size of structure (D) of 20 to 40μm.

3. An austenitic stainless steel excellent in flexibility being **characterized by** comprising:

   by weight percent, 0.1 to 0.65% of Si, 1.0 to 3.0% of Mn, 6.5 to 10.0% of Ni, 16.5 to 18.5% of Cr, 6.0% or less of Cu (excluding 0), 0.13% or less of (C + N) (excluding 0), and the remainder comprising Fe and unavoidable impurities,
   wherein the work hardening formula H2 defined by the following formula is 300 or less.

$$H2 = 4.27 + 0.875(-459 + 79.8Si - 10.2Mn - 8.16Ni + 48.0Cr - 13.2Cu + 623(C+N)) - 287D \text{ (D: the size of structure)}$$

4. The austenitic stainless steel excellent in flexibility according to claim 3, being **characterized by** having the size of structure (D) of 20 to 300μm.

5. An austenitic stainless steel excellent in flexibility being **characterized by** comprising:

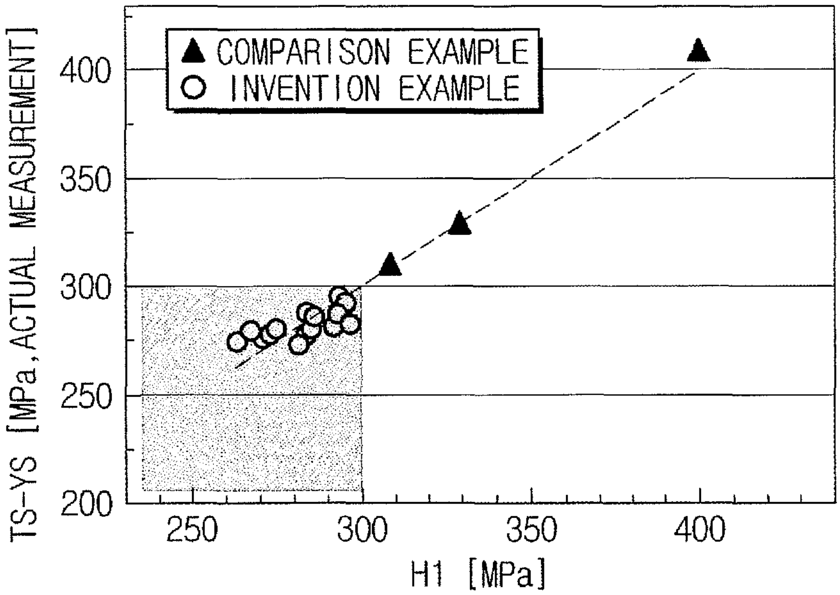
by weight percent, 0.1 to 0.65% of Si, 1.0 to 3.0% of Mn, 6.5 to 10.0% of Ni, 16.5 to 18.5% of Cr, 6.0% or less of Cu (excluding 0), 0.13% or less of (C + N) (excluding 0), and the remainder comprising Fe and unavoidable impurities,
wherein M_{d30} defined by the following formula is 0 or less.

$$M_{d30} = 551 - 462(C+N) - 9.2Si - 8.1Mn - 29(Ni+Cu) - 13.7Cr$$

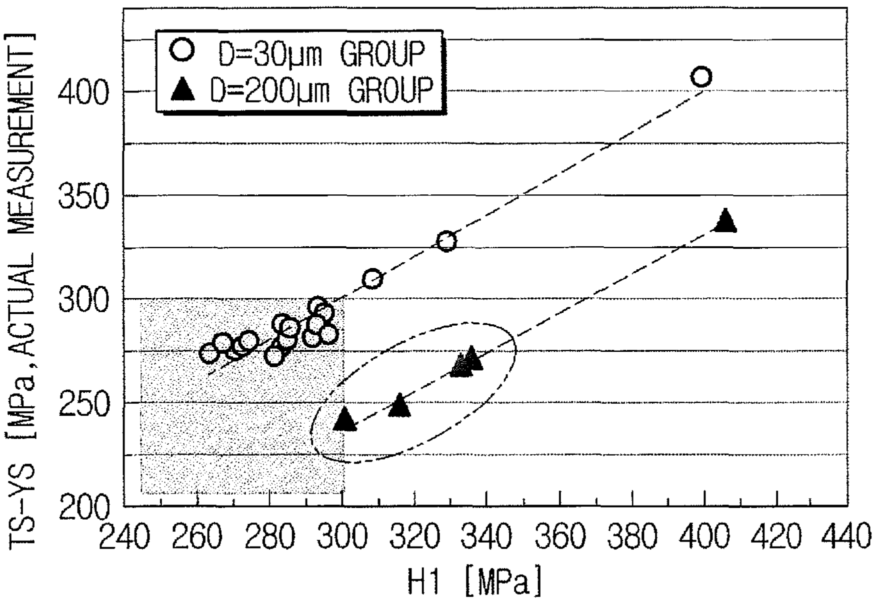
6. The austenitic stainless steel excellent in flexibility according to claim 5, wherein M_{d30} is -100 to 0.

7. The austenitic stainless steel excellent in flexibility according to any one of claims 1 to 6, wherein the difference value between TS (tensile strength) and YS (yield strength) is 300MPa or less.

【Fig. 1】


▲ COMPARISON EXAMPLE
○ INVENTION EXAMPLE
TS-YS [MPa, ACTUAL MEASUREMENT]
H1 [MPa]
200
250
300
350
400
250
300
350
400

【Fig. 2】


○ D=30μm GROUP
▲ D=200μm GROUP
TS-YS [MPa, ACTUAL MEASUREMENT]
H1 [MPa]
200
250
300
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400
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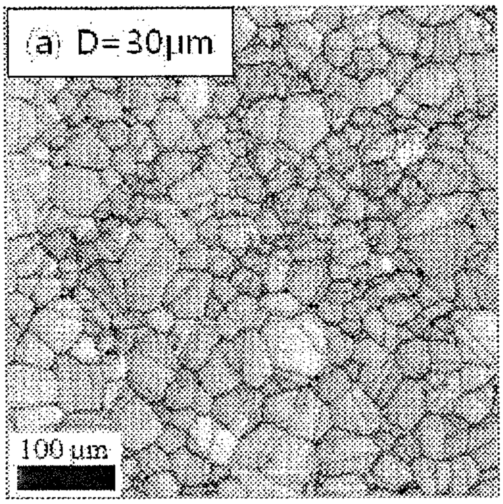
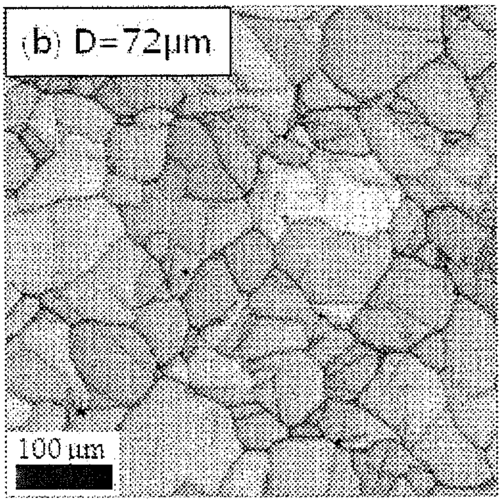
260
280
300
320
340
360
380
400
420
440

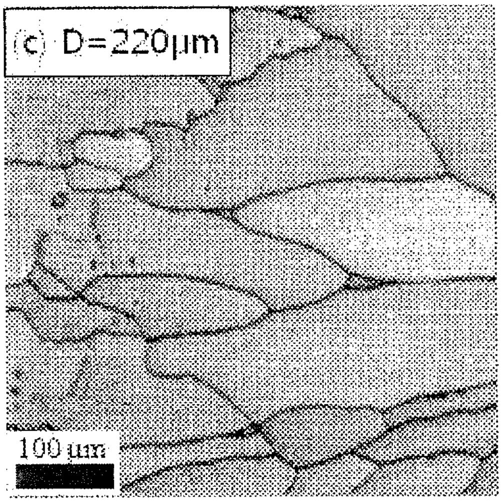
【Fig. 3】



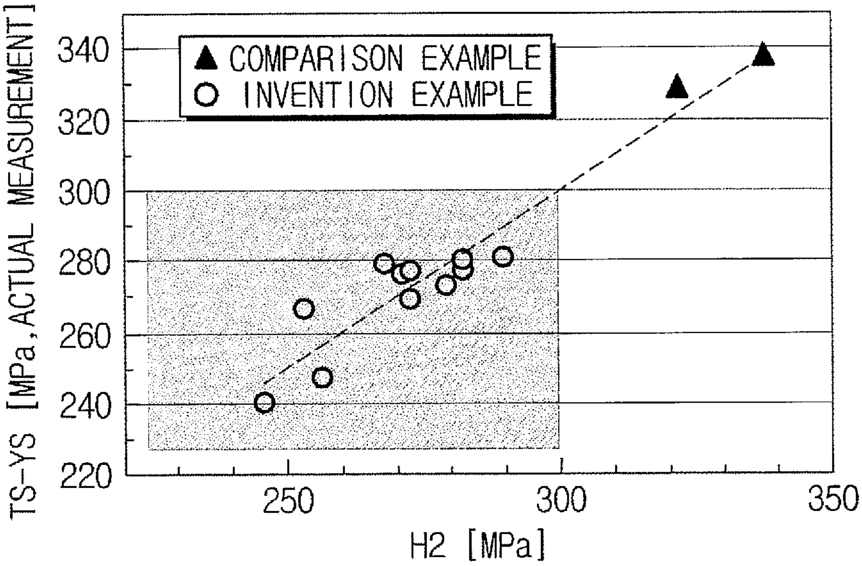
【Fig. 4】



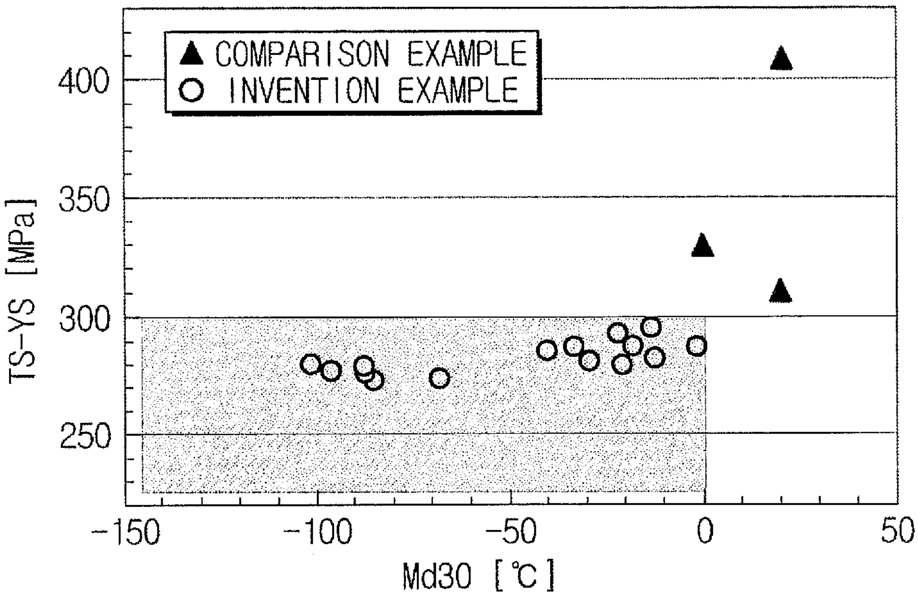
【Fig. 5】


(c) D=220μm
100 μm

【Fig. 6】


▲ COMPARISON EXAMPLE
○ INVENTION EXAMPLE
TS-YS [MPa, ACTUAL MEASUREMENT]
340
320
300
280
260
240
220
250
300
350
H2 [MPa]

【Fig. 7】


COMPARISON EXAMPLE
INVENTION EXAMPLE
400
350
300
250
TS-YS [MPa]
-150
-100
-50
0
50
Md30 [℃]

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2015/012973

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/58(2006.01)i, C22C 38/42(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/58; C21D 6/00; C22C 38/00; C22C 38/18; C22C 38/38; C22C 38/40; C22C 38/04; C22C 38/42

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS (KIPO internal) & Keywords: flexibility, austenite-based, stainless steel, processing hardness, yield strength, tensile strength

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 5448023 B2 (NATIONAL INSTITUTE FOR MATERIALS SCIENCE) 19 March 2014 See abstract; paragraph [0034]; claim 1; and tables 3, 5, 7, 9.	1-7
A	KR 10-2014-0080347 A (POSCO) 30 June 2014 See abstract; and claims 1, 4.	1-7
A	KR 10-2010-0069875 A (POSCO) 25 June 2010 See abstract; paragraph [0036]; and claim 1.	1-7
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Date of the actual completion of the international search	Date of mailing of the international search report
10 MARCH 2016 (10.03.2016)	**11 MARCH 2016 (11.03.2016)**

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