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(54) **PRECIPITATION-HARDENING-TYPE AUSTENITIC ALLOY STEEL MATERIAL AND METHOD FOR MANUFACTURING SAME, AND PRECIPITATION-HARDENING-TYPE AUSTENITIC ALLOY HEAT-TREATED STEEL MATERIAL AND METHOD FOR MANUFACTURING SAME**

(57) Provided is a method for manufacturing an austenitic alloy steel material that can improve mechanical properties even without improving a composition of a steel material and an increase in the service life of a component in a high-pressure hydrogen environment can be expected. A method for manufacturing a precipitation-hardening austenitic alloy steel material, the method including: a hot forging step of providing a material for

forging having a composition of the precipitation-hardening austenitic alloy steel material, and performing hot forging several times so that a total forging forming ratio is 30 or more, to form a forged material. The method preferably includes a heat treatment step of additionally subjecting the forged material to a solution treatment and an aging treatment, to obtain a heat-treated steel material.

FIG. 1



Description

TECHNICAL FIELD

[0001] The present invention relates to a method for manufacturing a precipitation-hardening austenitic alloy steel material, a method for manufacturing a precipitation-hardening austenitic alloy heat-treated steel material, a precipitation-hardening austenitic alloy steel material, and a precipitation-hardening austenitic alloy heat-treated steel material.

BACKGROUND ART

[0002] Since precipitation-hardening austenitic alloys such as SUH660 have good strength characteristics over a wide range of temperatures and are also excellent in hydrogen embrittlement resistance in a hydrogen environment, the precipitation-hardening austenitic alloys are known as suitable components for use in hydrogen stations (hydrogen stands). For example, Patent Document 1 describes that the A286 alloy (material corresponding to SUH660) suitable for hydrogen energy equipment is forged at a total forging ratio of 5:1 to obtain a forged product.

[0003] The precipitation-hardening austenitic alloys as described above are excellent in hydrogen embrittlement resistance. However, the presence of hydrogen causes localization of deformation due to plastic deformation in high-temperature environments or in high-pressure hydrogen gas and stacking faults are likely to be formed. Such defects are likely to be the cause of cracking, and mechanical properties such as tensile strength tend to be lower than in air. For example, Non-Patent Document 1 describes that when a precipitation-increased A286 test piece was subjected to hydrogen charging, the properties such as tensile strength of the test piece decreased as the hydrogen content increased. In this context, even the precipitation-hardening austenitic alloys are required to have higher strength of the materials. Non-Patent Document 2 describes that the composition of the A286 alloy is improved to increase its strength in order to suppress the precipitation of the η layer that increases hydrogen embrittlement sensitivity.

REFERENCE DOCUMENT LIST

PATENT DOCUMENT

[0004] Patent Document 1: CN 11354982 A

NON-PATENT DOCUMENTS

[0005]

Non-Patent Document 1: Naoki Tajima, five others, "Effect of Internal Hydrogen on Tensile Properties of Iron-Based Superalloy SUH 660", transactions of the JSME (series A), 2012, August, Vol. 78, No. 792, pp. 50-64

Non-Patent Document 2: Shinya Sato, three others, "Development of a Modified A286 Alloy with Improved Strength at Elevated Temperature and Evaluation of its Hydrogen Embrittlement Susceptibility", Technical report of The Japan Steel Works, Ltd., The Japan Steel Works, Ltd., 2014, December, No. 65, pp. 76-81

SUMMARY OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0006] The method described in Non-Patent Document 2 is effective in improving mechanical properties such as strength at high temperatures. However, there is a concern that ductility such as elongation may decrease as strength is improved. In addition, in Non-Patent Document 2, a relatively large amount of W is contained to improve properties, but W is an expensive material. Therefore, W is one of the materials that should be avoided as much as possible in products for industrial applications. Thus, an object of the present invention is to provide a method for manufacturing a precipitation-hardening austenitic alloy steel material and a precipitation-hardening austenitic alloy heat-treated steel material that can improve mechanical properties without improving the composition of the steel material and can expect longer service life of a component in a high-pressure hydrogen environment.

MEANS FOR SOLVING THE PROBLEM

[0007] The present invention has been made in view of the above-mentioned problems.

[0008] That is, one aspect of the present invention is a method for manufacturing a precipitation-hardening austenitic

alloy steel material, the method including: a hot forging step of providing a material for forging having a composition of the precipitation-hardening-austenitic alloy, and performing hot forging several times so that a total forging forming ratio is 30 or more, to form a forged material, the forged material having a columnar shape and an equivalent area diameter of a cross section in a direction perpendicular to an axis of the forged material being 100 mm or more.

[0009] Another aspect of the present invention is a method for manufacturing a precipitation-hardening austenitic alloy heat-treated steel material, the method including a heat treatment step of additionally subjecting the forged material to a solution treatment and an aging treatment, to obtain a heat-treated material.

[0010] Another aspect of the present invention is a precipitation-hardening austenitic alloy steel material, of which an area ratio of grains having a GOS (Grain Orientation Spread) value of 1.0° or more is 50% or more, and of which a shape is columnar, an equivalent area diameter of a cross section in a direction perpendicular to an axis of the precipitation-hardening austenitic alloy steel material being 100 mm or more.

[0011] Another aspect of the present invention is a precipitation-hardening austenitic alloy heat-treated steel material, which has a grain size number of 4.0 or more, a 0.2% yield strength of 590 MPa or more, a tensile strength of 900 MPa or more, and an elongation of 15% or more at positions of depth D/4 and depth D/2 from the surface of the heat-treated steel material, when an equivalent area diameter of a cross section in a direction perpendicular to an axis of the heat-treated steel material is designated as D, and of which a shape is columnar, an equivalent area diameter of a cross section in a direction perpendicular to an axis of the precipitation-hardening austenitic alloy heat-treated steel material being 100 mm or more.

EFFECTS OF THE INVENTION

[0012] According to the present invention, it is possible to manufacture a precipitation-hardening austenitic alloy steel material and a precipitation-hardening austenitic alloy heat-treated steel material that can further improve mechanical properties and to expect an increase in the service life in a high-pressure hydrogen environment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

FIG. 1 is a schematic view for explaining a forging forming ratio.

FIG. 2 is a schematic view for explaining another forging forming ratio.

FIG. 3 is a schematic view that shows a position at which a sample for measuring mechanical properties is collected in Examples.

FIG. 4 is a schematic view that shows a position at which a sample for EBSD is collected in Examples.

MODE FOR CARRYING OUT THE INVENTION

[0014] Hereinafter, the present invention will be described in detail. However, the present invention is not limited to the embodiments described herein, and appropriate combinations and improvements can be made without departing from the technical concept of the invention. The present invention is directed to a precipitation-hardening austenitic alloy steel material. This precipitation-hardening austenitic alloy steel material refers to SUH309, SUH310, SUH330, SUH660, SUH661, and improved materials thereof described in JIS-G-4311. Specifically, the precipitation-hardening austenitic alloy steel material includes: % by mass, Ni: 10 to 40%, and Cr: 10 to 30%, and preferably includes: % by mass, 95% or more of Fe + Ni + Cr. In addition, the precipitation-hardening austenitic alloy steel material can include: Ni: 10 to 40%, Cr: 10 to 30%, and the balance: Fe and inevitable impurities.

[0015] The lower limit of the amount of Ni is more preferably 20% by mass, and the upper limit of the amount of Ni is more preferably 30% by mass. The upper limit of Cr is more preferably 20% by mass. In addition, in order to improve hardness and strength at high temperatures, up to 5.0% by mass in total of one or two or more of elements selected from V, Si, Mn, Al, B, Ta, W, Ti, Mo, and Nb may be contained. Moreover, examples of inevitably contained impurity elements include C, S, P, and O. The upper limit of each of these elements is preferably, for example, 0.1%.

[0016] In the manufacturing method of the present embodiment, a material for forging having a composition of the precipitation-hardening austenitic alloy is provided. This material for forging is preferably a steel ingot that can be obtained by casting. When the steel ingot is subjected to hot plastic working such as hot press or hot rolling and is then subjected to a homogenization heat treatment to form a semi-finished product that is mechanically processed to have a shape of cylindrical or square bar (billet, bloom, etc.), this semi-finished product may be a material for forging. When the steel ingot is manufactured, remelting may be performed in order to reduce component segregation or non-metallic inclusions.

[0017] Then, the provided material for forging as described above is heated in a heating furnace, and hot forging is performed several times, to obtain a precipitation-hardening austenitic alloy steel material. In the present invention, when

this hot forging is performed, forging is performed so that a total forging forming ratio (hereinafter, may also be described as total forging ratio) is 30 or more. This makes it possible to introduce processing strain to the center of the forged material, and to cause recrystallization with dynamic recrystallization, to improve mechanical properties of the forged material. Note that, the "total forging forming ratio (total forging ratio)" in the present invention is obtained by using a forging forming ratio of solid forging described in JIS-G-0701. For example, the hot forging shown in FIG. 1 is performed, the equation of $((S_0/S_1) \times (S_1/S_2) \times \cdots \times (S_{n-1}/S_n))$ is the total forging forming ratio. In the above equation, $S_0, S_1, S_2, \cdots, S_{n-1}, S_n$ is a cross-sectional area. As a processing example in which the total forging ratio is more than 30, in a case in which a cylindrical bar having a diameter of 100 mm is a material for forging, when the solid forging (from a diameter of 100 mm to a diameter of 50 mm) and the solid forging (from a diameter of 50 mm to a diameter of 18 mm) are performed, the total forging forming ratio is 30.8, which satisfies the requirements of the present invention. The lower limit of the total forging ratio is preferably 35, and the lower limit of the total forging ratio is more preferably 40. The upper limit of the total forging ratio is not particularly limited. However, since the more times the forging is performed, the higher the manufacturing costs, the upper limit of the total forging ratio is realistically, for example, 200, but it may be 150.

[0018] In the present embodiment, in order to increase the total forging ratio without significantly decreasing the size of the forged material, upset forging is preferably performed at least one time or more. In the present embodiment, the processing strain imparted by the solid forging tends to mainly contribute to improvement of mechanical properties. Therefore, in the present embodiment, when the upset forging is performed, the total forging ratio is calculated without including the forging forming ratio (upset forging ratio) at the time of upset forging. For example, the hot forging shown in FIG. 2 is performed (S_1-S_2 is upset forging), the equation of $((S_0/S_1) \times (S_2/S_3) \times \cdots \times (S_{n-1}/S_n))$ is the total forging forming ratio. Combination of upset forging makes it possible to sufficiently introduce processing strain in a large forged product having an equivalent area diameter of 100 mm or more. The temperature of the heating furnace at the time of forging is preferably 800 to 1300°C, and the surface temperature of the material at the completion of forging is preferably 600°C or more.

[0019] The "hot forging" in the present invention preferably includes hot free forging in which a material to be processed is placed on an anvil having a flat or curved surface and the material is processed with a hammer also having a flat or curved surface, from the viewpoint of the freedom of shape to be processed. Of course, when the material is processed into a material with a complex shape, closed die forging may be performed using a die, radial forging may be performed in which the material is rotated in the circumferential direction while being pressed from four directions over the entire length of the material to obtain a forged material, or a combination of these processes may be used. In addition, the processing that combines blooming with hot forging may be performed. When blooming is performed, the total forging forming ratio can be calculated by measuring the cross-sectional areas before and after rolling and applying them to the equation for obtaining the forming forging ratio of the solid forging described above.

[0020] In order to achieve the total forging ratio of the present embodiment as described above, the solid forging is preferably performed at least three times. The reason for this is because the deformation resistance of the precipitation-hardening austenitic alloy steel material is large, and therefore, a smaller processing ratio per forging enables stable processing. The number of upset forgings is preferably at least two times in order to introduce processing strain to the inside of a large forged product having an equivalent area diameter of 100 mm or more.

[0021] In the present embodiment, the forged product obtained in the hot forging step (i.e., precipitation-hardening austenitic alloy steel material) is subjected to a solution treatment and an aging treatment, to obtain a precipitation-hardening austenitic alloy heat-treated steel material. This suppresses the variation in grain size of the steel material, resulting in a uniform fine-grained microstructure and further improving the mechanical strength of the product. The temperature of the solution treatment is preferably 850 to 1050°C, and more preferably 900 to 1000°C. The temperature of the aging treatment is preferably 650 to 800°C, and more preferably 700 to 760°C.

[0022] Then, the precipitation-hardening austenitic alloy steel material of the present invention, which can be obtained by the manufacturing method of the present invention, will be described. In the precipitation-hardening austenitic alloy steel material of the present invention, an area ratio of grains having a GOS (Grain Orientation Spread) value of 1.0° or more is 50% or more. The area ratio is preferably 60% or more. This GOS value can be measured by conventionally known "SEM-EBSD method (electron backscatter diffraction)", and can be obtained by calculating the misorientation of points (pixels) constituting a grain. The crystal misorientation obtained by the GOS value is an indicator showing strain in an alloy imparted by processing. When an area ratio of grains having a GOS value of 1.0° or more is 50% or more, a uniform fine-grained microstructure having a small variation in grain size tends to be easily obtained after the solution treatment. In addition, there are fewer coarse unrecrystallized grains that are not imparted with processing strain, and the mechanical properties, especially the 0.2% yield strength, tend to be improved. When an area ratio of grains having a GOS value of 1.0° or more is less than 50%, the above-mentioned coarse, unrecrystallized grains increase, and this may possibly decrease mechanical properties such as 0.2% yield strength. The GOS value in this embodiment can be obtained by collecting a sample at positions of depths D/4 and D/2 from the surface of the forged material in the axial direction (D is the distance between the surfaces passing through the axis, e.g., equivalent to the diameter) and measuring them. In addition, the cross section for observing the area ratio includes a cross section perpendicular to the axis and a cross section in the axial

direction, but it is preferable that the area ratio of grains having a GOS value of 1.0° or more be 50% or more when a bar material is observed for both the section perpendicular to the axis and the cross section in the axial direction. Note that the GOS value in the present invention is a value obtained by measuring a sample collected from a forged material (before the solution treatment and the aging treatment). Furthermore, the area ratio of grains having a GOS value of 1.0° or more after the solution heat treatment and the aging heat treatment tends to be a low value of less than 50%, since the strain caused by forging is released. In this embodiment, the GOS value described above may be measured by collecting a test piece from the surface of the obtained forged material at a depth of $D/4$ (D : diameter of an equivalent area diameter) and at a depth of $D/2$ in the axial direction in the direction shown in FIG. 3. In particular, the position of depth $D/2$ corresponds to the center of the steel material and is the position where strain is least likely to occur. Therefore, the test piece collected at the position of depth $D/2$ also preferably satisfies the characteristics specified in the present invention.

[0023] The precipitation-hardening austenitic alloy steel material of the present invention is directed to a steel material having a columnar shape and 100 mm or more of an equivalent area diameter of a cross section in a direction perpendicular to an axis of the precipitation-hardening austenitic alloy steel material. Regarding the steel material of the present invention obtained by the manufacturing method of the present invention described above, processing strain is introduced to the center of the material even in a large steel material having an equivalent area diameter of 100 mm or more (preferably 200 mm or more, 300 mm or more, 400 mm or more). Here, the "columnar shape" refers to, for example, a circular column shape or a rectangular column shape, and may be tapered in the axial direction. When the taper is formed, the equivalent area diameter of the cross section in the direction perpendicular to the axis of the present invention may be obtained by measuring the cross section perpendicular to the axis at a position of $L/2$, where L is the length of the steel material.

[0024] The precipitation-hardening austenitic alloy heat-treated steel material of the present invention obtained by the manufacturing method of the present invention (material that has experienced the solution heat treatment and the aging treatment) preferably has a grain size number of 4.0 or more. As described above, since the precipitation-hardening austenitic alloy steel material before the solution heat treatment and the aging treatment has 50% or more of grains having a GOS value of 1.0° or more, coarse unrecrystallized grains are hardly formed after the solution heat treatment and the aging treatment, and a uniform fine-grained microstructure tends to be easily obtained. When the grain size number of 4.0 or more is maintained, the precipitation-hardening austenitic alloy steel material having good mechanical properties: a 0.2% yield strength of 590 MPa or more, a tensile strength of 900 MPa or more, and an elongation of 15% or more can be obtained. A preferable 0.2% yield strength is 600 MPa or more, a more preferable 0.2% yield strength is 630 MPa or more, and a still more preferable 0.2% yield strength is 660 MPa or more. A preferable tensile strength is 950 MPa or more, and a more preferable tensile strength is 980 MPa or more. The lower limit of an elongation is preferably 20%, and the upper limit of an elongation is preferably 30%. The upper limit of the grain size number is not particularly limited. However, in order to obtain excessively fine grains, the forging ratio must be set to an excessively large value, which makes manufacturing difficult. Therefore, the upper limit may be set to, for example, 10.0. The upper limit of the grain size number is preferably 8.0, and the upper limit of the grain size number is more preferably 7.0. In particular, the 0.2% yield strength is affected by the grain size, and tends to decrease due to the presence of coarse, unrecrystallized grains that have not been imparted with sufficient processing strain. However, with the steel material of the present invention obtained by the manufacturing method of the present invention, a good value can be obtained without decreasing the 0.2% yield strength. The grain size, the 0.2% yield strength, the tensile strength, and the elongation as described in the present embodiment are measured in the same manner as the GOS value, by collecting a test piece from the surface of the obtained forged material at positions of depths $D/4$ (D : diameter of equivalent area diameter) and $D/2$ in the axial direction in the direction as shown in FIG. 3. In particular, the position of depth $D/2$ corresponds to the center of the steel material and is the position where it is less likely to strain, and a uniform fine-grained microstructure is thus hardly obtained. Therefore, the test piece collected at the position of depth $D/2$ also preferably satisfies the requirements specified in the present invention.

EXAMPLES

[0025] The present invention will be described in more detail by way of the following Examples.

Example 1

[0026] Steel ingots having a composition shown in Table 1 (material corresponding to SUH660) were provided to form columnar materials for forging for Examples of the present invention and Comparative Examples. Each of the columnar materials was subjected to hot forging. In Examples of the present invention, the material for forging was subjected to solid forging and upset forging several times so that the total forging ratio would be 101, to thereby obtain a forged material in which an equivalent area diameter of a cross section in a direction perpendicular to the axis of the columnar material was 470 mm. In Comparative Examples, the material for forging was subjected to solid forging and upset forging several times so that the total forging ratio would be 26, to thereby obtain a forged material in which an equivalent area diameter of a cross

section in a direction perpendicular to the axis of the columnar material was 620 mm. Then, from the surface of the obtained forged material, test pieces ($13 \times 13 \times 100$ mm) were collected in the axial direction at the position of depth D/4 (D: diameter of equivalent area diameter) and the position of D/2 in the axial direction, in the direction shown in "MATERIAL COLLECTED FROM AXIAL DIRECTION" in FIG. 3, and were subjected to the solution treatment and the aging treatment, to obtain heat-treated materials. Then, various mechanical properties and grain size numbers were measured. The test pieces used to measure various mechanical properties were JIS 14A test pieces specified in JIS Z2241, and measurements were performed based on the tensile test method for metallic materials in JIS Z2241. The grain size number was determined using grain size standard plate 1 according to JIS-G-0551. The heat treatment conditions, and the results of various mechanical properties and grain size numbers are shown in Table 2.

[0027] It was confirmed from Table 2 that all the samples of Examples of the present invention have higher 0.2% yield strength and tensile strength than Comparative Examples, have a similar level of elongation, and have excellent mechanical properties. In addition, it was confirmed that the grain sizes of the samples of Examples of the present invention was finer than Comparative Examples, and have smaller variation in grain size than Comparative Examples.

Table 1

C	Si	Mn	Ni	Cr	Mo	V	Al	Ti	B	Balance
0.04	0.05	0.05	25.27	14.86	1.32	0.29	0.30	1.95	0.0032	Fe and inevitable impurities

Table 2

Sample No.	Total forging ratio	Temperature of solution heat treatment [°C]	Temperature of aging treatment [°C]	0.2% yield strength [MPa]		Tensile strength [MPa]		Elongation [%]		Grain size number		Remarks
				D/2	D/4	D/2	D/4	D/2	D/4	D/2	D/4	
No. 1	101	900	718	716	736	1046	1054	27.1	24.8	4.0	5.0	Examples of the present invention
No. 2	101	965	718	717	733	1047	1058	25.6	25.6	4.0	5.0	
No. 3	101	982	718	715	597	1047	1025	25.3	28.1	4.0	4.5	
No. 4	101	900	760	717	725	995	990	23.7	25.6	4.0	5.0	
No. 5	101	965	760	713	717	994	991	23.7	24.2	4.0	5.0	
No. 6	101	982	760	716	641	997	971	24.0	24.8	4.0	5.5	
No. 101	26	900	718	542	558	969	988	29.9	29.1	2.5	3.5	Comparative Examples
No. 102	26	965	718	523	526	962	973	32.6	32.6	2.5	3.0	
No. 103	26	982	718	577	515	857	964	14.5	31.6	2.5	2.5	
No. 104	26	900	760	477	657	803	964	19.7	25.4	2.0	3.0	
No. 105	26	965	760	489	643	800	959	11.9	24.9	1.5	3.0	
No. 106	26	982	760	562	644	912	961	23.8	26.4	3.0	3.0	

[0028] Regarding the forged material of the present invention, test pieces were collected from the surface in the direction perpendicular to the axis at the position of depth D/4 and the position of D/2 in the axial direction, in the direction shown in "MATERIAL COLLECTED FROM AXIAL DIRECTION" in FIG. 3, and were subjected to the solution treatment and the aging treatment, to obtain heat-treated materials. Then, various mechanical properties were measured. The heat treatment conditions and the results of various mechanical properties are shown in Table 3. From Table 3, it was confirmed that the various mechanical properties of the samples collected in the direction perpendicular to the axis of the present invention have excellent mechanical properties at the same level as those obtained in the axial direction.

Table 3

Sample No.	Total forging ratio	Temperature of solution heat treatment [°C]	Temperature of aging treatment [°C]	0.2% yield strength [MPa]		Tensile strength [MPa]		Elongation [%]		Remarks
				D/2	D/4	D/2	D/4	D/2	D/4	
7	101	900	718	717	713	1022	1031	22.4	22.1	Examples of the present invention
8	101	965	718	713	725	1015	1030	23.7	22.2	
9	101	982	718	705	616	1023	1003	21.6	23.0	
10	101	900	760	713	730	966	974	20.6	21.7	
11	101	965	760	715	727	968	978	24.0	21.4	
12	101	982	760	711	682	970	966	21.2	23.4	

[0029] Next, two types of samples were collected in the axial direction and the direction perpendicular to the axial direction at the positions of depths D/4 and D/2 in the axial direction, from the surface of the forged material (before heat treatment) obtained in the Examples of the present invention and the Comparative Examples, respectively, and the GOS value of each sample was observed. The GOS value was measured by observing the longitudinal section (cross section in the axial direction) and the transverse section (cross section perpendicular to the axis) of the sample using a field emission scanning electron microscope manufactured by ZEISS and an EBSD measurement and analysis system OIM (Orientation-Imaging-Micrograph) manufactured by TSL, and samples for measurement (11 × 10 × 5 mm) were collected from each cross section as shown in FIG. 4. The surface to be measured was 11 × 10 mm, the measurement field of view was 1500 μm × 1500 μm, and the step distance between adjacent pixels was 3.0 μm. In addition, observation was performed under conditions that allowed boundaries with a misorientation of 5° or more between adjacent pixels to be identified as grain boundaries, and the area ratio of grains with a GOS value of 1.0° or more to the entire observation field was calculated from the obtained GOS value map. The observation results are shown in Table 4. From the results in Table 4, the occupancy rate of GOS values of 1.0° or more in both the longitudinal and transverse sections of the Examples of the present invention was 50% or more, the variation in grain size was small, and the 0.2% yield strength, tensile strength, and elongation in the axial direction and the direction perpendicular to the axis after heat treatment were all good.

Table 4

Sample No.	Total forging ratio	Area ratio of grains having 1.0° or more of GOS value [%]				Remarks
		Longitudinal section		Transverse section		
		D/2	D/4	D/2	D/4	
13	101	62.2	94.9	81.1	66.7	Example of the present invention
14	26	27.6	32.6	0.7	1.3	Comparative Example

Example 2

[0030] Steel ingots having a composition shown in Table 5 (material corresponding to SUH660) were provided to form columnar materials for forging for Examples of the present invention. Each of the columnar materials was subjected to hot forging. In Examples of the present invention, the material for forging was subjected to solid forging and upset forging several times so that the total forging ratio would be 38 or 50, to thereby obtain forged materials in which equivalent area diameters of cross sections perpendicular to the axis of the columnar materials were 500 mm and 440 mm. Then, from the

surface of the obtained forged material that had experienced the solution treatment and the aging treatment, test pieces were collected in the axial direction at the position of depth D/4 in the axial direction. Then, various mechanical properties and grain size numbers were measured. The results of various mechanical properties and the grain size numbers are shown in Table 6. It is indicated that, since the yield strengths measured in Sample No. 15 and Sample No. 16 as the present invention are the yield strength when the strain is at 0.1% (0.1% yield strength), the 0.2% yield strength of No. 15 is 605 MPa or higher and the 0.2% yield strength of No. 16 is 600 MPa or more. It was confirmed that the samples of Examples of the present invention had higher 0.2% yield strength and tensile strength than Comparative Examples in Example 1, and had excellent mechanical properties.

Table 5

C	Si	Mn	Ni	Cr	Mo	V	Al	Ti	B	Balance
0.04	0.09	0.12	25.34	14.82	1.36	0.30	0.35	2.08	0.0037	Fe and inevitable impurities

Table 6

Sample No.	Total forging ratio	Temperature of solution heat treatment [°C]	Temperature of aging treatment [°C]	0.1% yield strength [MPa]	Tensile strength [MPa]	Elongation [%]	Grain size number	Remarks
15	38	980	718	605	1031	28.1	4.0	Example of the present invention
16	50	980	718	600	1046	27.2	-	Example of the present invention

Example 3

[0031] A steel ingot having a composition shown in Table 7 (material corresponding to SUH660) was provided to form a columnar material for forging for an Example of the present invention. The columnar material was subjected to hot forging. In Example of the present invention, the material for forging was subjected to solid forging and upset forging several times so that the total forging ratio would be 63, to thereby obtain a forged material in which an equivalent area diameter of a cross section in a direction perpendicular to the axis of the columnar material was 200 mm. Then, from the surface of the obtained forged material that had experienced the solution treatment and the aging treatment, a test piece was collected in the axial direction at the position of depth D/4 in the axial direction. Then, various mechanical properties and grain size numbers were measured. The results of various mechanical properties and the grain size numbers are shown in Table 8. It is indicated that, since the yield strength measured in Sample No. 17 as the present invention is the yield strength when the strain is at 0.1% (0.1% yield strength), the 0.2% yield strength of No. 17 is 644 MPa or more. It was confirmed that the sample of Example of the present invention had higher 0.2% yield strength and tensile strength than Comparative Examples in Example 1, and had excellent mechanical properties.

Table 7

C	Si	Mn	Ni	Cr	Mo	V	Al	Ti	B	Balance
0.04	0.11	0.13	25.58	14.92	1.36	0.30	0.28	2.11	0.0033	Fe and inevitable impurities

[Table 8]

Sample No.	Total forging ratio	Temperature of solution heat treatment [°C]	Temperature of aging treatment [°C]	0.1% yield strength [MPa]	Tensile strength [MPa]	Elongation [%]	Grain size number	Remarks
17	63	980	720	644	1048	31.3	4.5	Example of the present invention

Claims

1. A method for manufacturing a precipitation-hardening austenitic alloy steel material, the method comprising: providing a material for forging having a composition of a precipitation-hardening austenitic alloy, and performing hot forging several times so that a total forging forming ratio is 30 or more, to form a forged material, the forged material having a columnar shape and an equivalent area diameter of a cross section in a direction perpendicular to an axis of the forged material being 100 mm or more.
2. A method for manufacturing a precipitation-hardening austenitic alloy heat-treated steel material, the method comprising: additionally subjecting the precipitation-hardening austenitic alloy steel material according to claim 1 to a solution treatment and an aging treatment, to obtain a heat-treated steel material.
3. A precipitation-hardening austenitic alloy steel material, wherein an area ratio of grains having a GOS (Grain Orientation Spread) value of 1.0° or more is 50% or more, wherein a shape of the precipitation-hardening austenitic alloy steel material is columnar, and an equivalent area diameter of a cross section in a direction perpendicular to an axis of the precipitation-hardening austenitic alloy steel material is 100 mm or more.
4. A precipitation-hardening austenitic alloy heat-treated steel material, wherein when an equivalent area diameter of a cross section in a direction perpendicular to an axis of the heat-treated steel material is designated as D, the precipitation-hardening austenitic alloy heat-treated steel material has a grain size number of 4.0 or more, a 0.2% yield strength of 590 MPa or more, a tensile strength of 900 MPa or more, and an elongation of 15% or more at positions of depth D/4 and depth D/2 from a surface of the heat-treated steel material, and a shape of the precipitation-hardening austenitic alloy heat-treated steel material is columnar, and an equivalent area diameter of a cross section in a direction perpendicular to an axis of the precipitation-hardening austenitic alloy heat-treated steel material is 100 mm or more.

FIG. 1

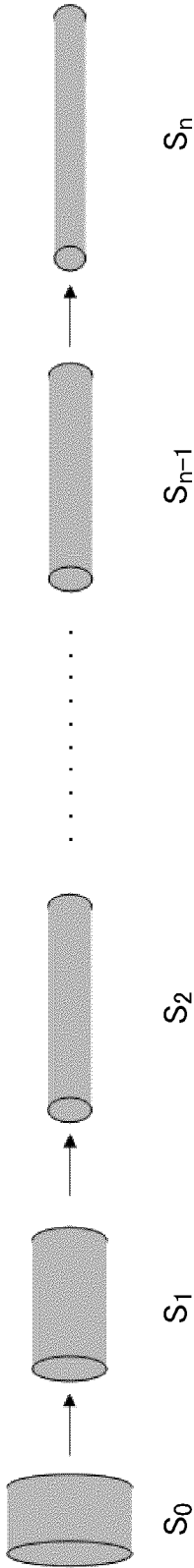


FIG. 2

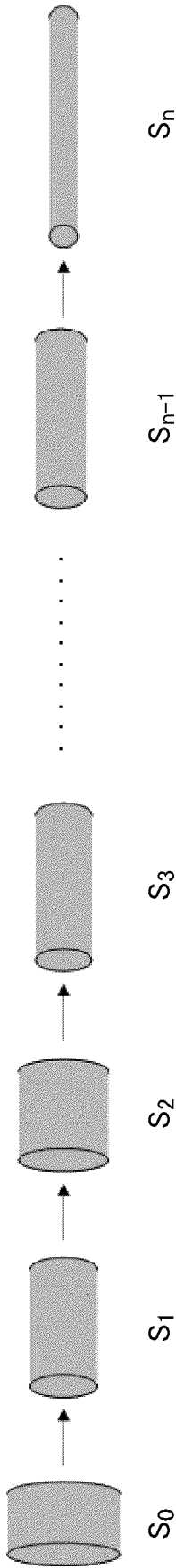
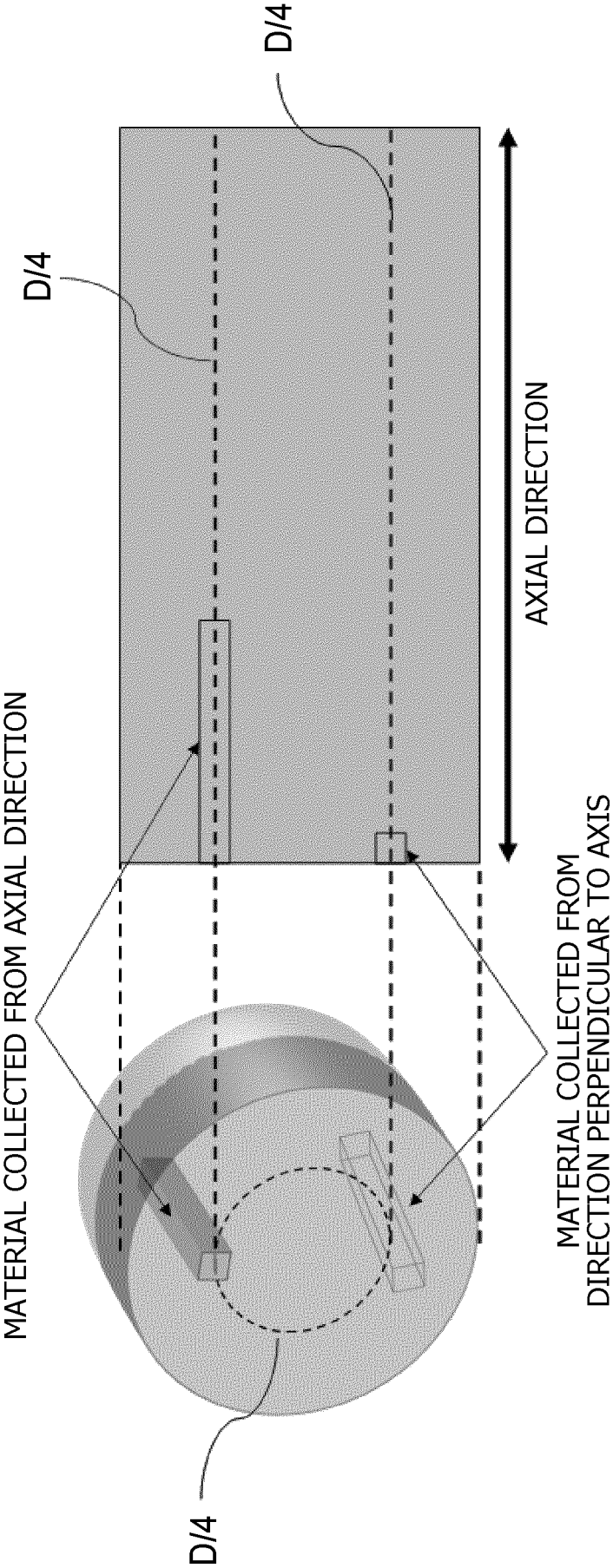
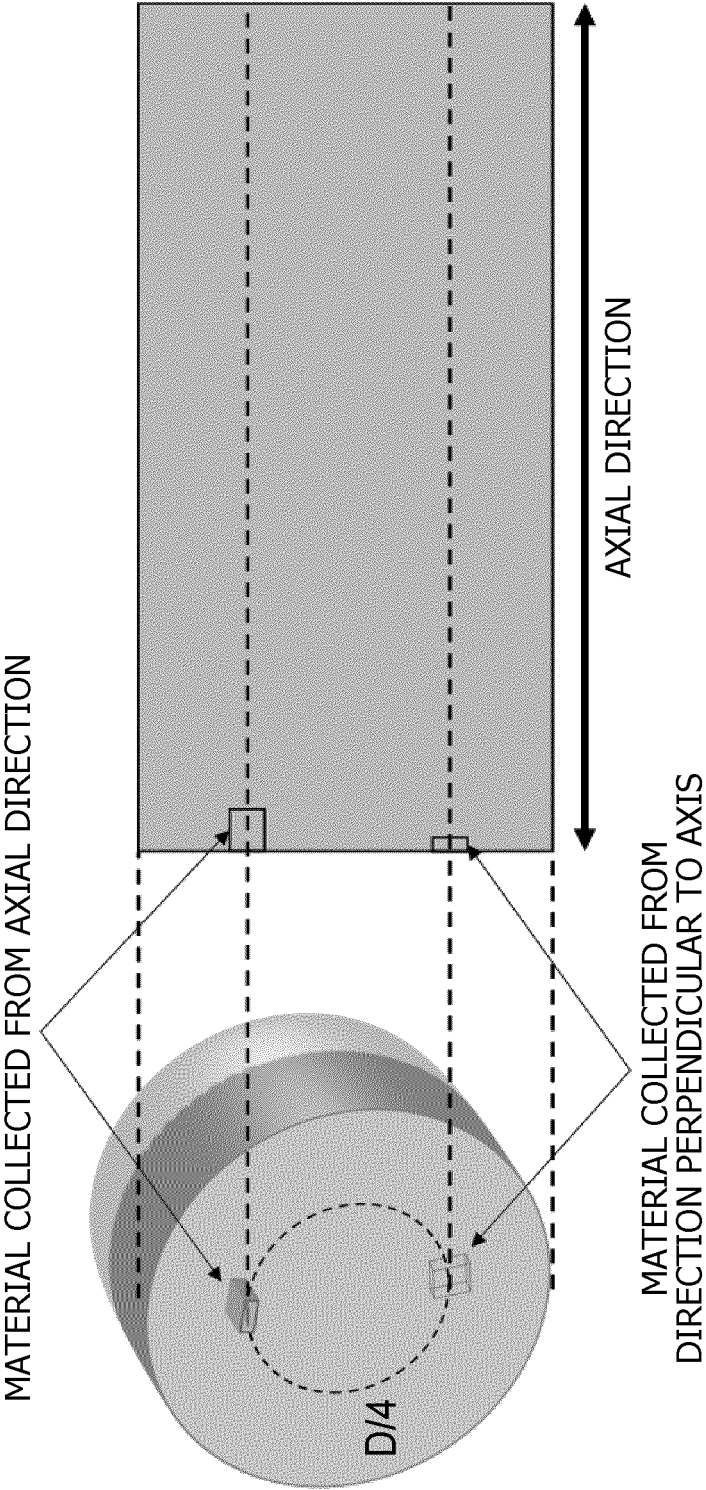


FIG. 3



SCHEMATIC VIEW OF TRANSVERSE SECTION SCHEMATIC VIEW OF LONGITUDINAL SECTION

FIG. 4



SCHEMATIC VIEW OF TRANSVERSE SECTION

SCHEMATIC VIEW OF LONGITUDINAL SECTION

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/000383

A. CLASSIFICATION OF SUBJECT MATTER

B21J 1/04(2006.01)i; **B21J 1/06**(2006.01)i; **C21D 6/00**(2006.01)i; **C21D 8/00**(2006.01)i; **C22C 30/00**(2006.01)i;
C22C 38/00(2006.01)i; **C22C 38/58**(2006.01)i; **C22C 38/60**(2006.01)i; **C22F 1/00**(2006.01)i; **C22F 1/16**(2006.01)i
 FE: C21D8/00 D; C22F1/00 630A; C22C38/58; B21J1/06 A; C22F1/16 Z; B21J1/04; C22C38/60; C22C30/00; C22F1/00
 602; C22F1/00 604; C22F1/00 624; C22C38/00 302Z; C22F1/00 630K; C22F1/00 640A; C22F1/00 640E; C22F1/00
 682; C22F1/00 683; C22F1/00 684C; C22F1/00 691B; C22F1/00 694A; C22F1/00 694B; C21D6/00 102S

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)

B21J1/04; B21J1/06; C21D6/00; C21D8/00; C22C19/03-C22C19/05; C22C30/00; C22C38/00-C22C38/60; C22F1/00;
 C22F1/16

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2023
 Registered utility model specifications of Japan 1996-2023
 Published registered utility model applications of Japan 1994-2023

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2006-334607 A (SUMITOMO METAL INDUSTRIES, LTD.) 14 December 2006 (2006-12-14) claims, paragraphs [0022], [0034]-[0039], [0041], [0045]-[0047], tables 1-4	1-4
A	JP 2017-36477 A (NIPPON STEEL & SUMITOMO METAL CORP.) 16 February 2017 (2017-02-16) entire text	1-4
A	WO 2016/152985 A1 (HITACHI METALS, LTD.) 29 September 2016 (2016-09-29) entire text, all drawings	1-4
A	JP 2016-74946 A (SANYO SPECIAL STEEL CO., LTD.) 12 May 2016 (2016-05-12) entire text	1-4

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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“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

17 March 2023

Date of mailing of the international search report

28 March 2023

Name and mailing address of the ISA/JP

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Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/000383

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 111235434 A (BEIJING CISRI GAONA TECHNOLOGY CO., LTD.) 05 June 2020 (2020-06-05) entire text, all drawings	1-4

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/000383

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2006-334607 A	14 December 2006	(Family: none)	
JP 2017-36477 A	16 February 2017	(Family: none)	
WO 2016/152985 A1	29 September 2016	JP 6120200 B2 entire text, all drawings	
JP 2016-74946 A	12 May 2016	(Family: none)	
CN 111235434 A	05 June 2020	US 2022/0119931 A1 entire text, all drawings	
		WO 2021/174727 A1	
		EP 3978640 A1	

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CN 11354982 A [0004]

Non-patent literature cited in the description

- **NAOKI TAJIMA**. Effect of Internal Hydrogen on Tensile Properties of Iron-Based Superalloy SUH 660. *transactions of the JSME (series A)*, August 2012, vol. 78 (792), 50-64 [0005]
- Development of a Modified A286 Alloy with Improved Strength at Elevated Temperature and Evaluation of its Hydrogen Embrittlement Susceptibility. **SHINYA SATO**. Technical report of The Japan Steel Works, Ltd.. The Japan Steel Works, Ltd., December 2014, 76-81 [0005]