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(71) Applicant: **Apogean Metal Co., Ltd.**
Taoyuan City 325 (TW)

(72) Inventors:
- **Chiang, Ming-Huang**
  325 Taoyuan City (TW)
- **Huang, Ting-Yi**
  325 Taoyuan City (TW)

(74) Representative: **V.O.**
P.O. Box 87930
Carnegieplein 5
2508 DH Den Haag (NL)

(54) **AUSTENITIC STEEL ALLOY FOR HOT FORMING**

(57) An austenitic steel alloy includes manganese in an amount of from 25 wt% to 31 wt%, aluminum in an amount of from 7 wt% to 10 wt%, carbon in an amount of from 1.2 wt% to 1.6 wt%, molybdenum in an amount of more than 0 wt% and less than 6 wt%, and a balance of iron.

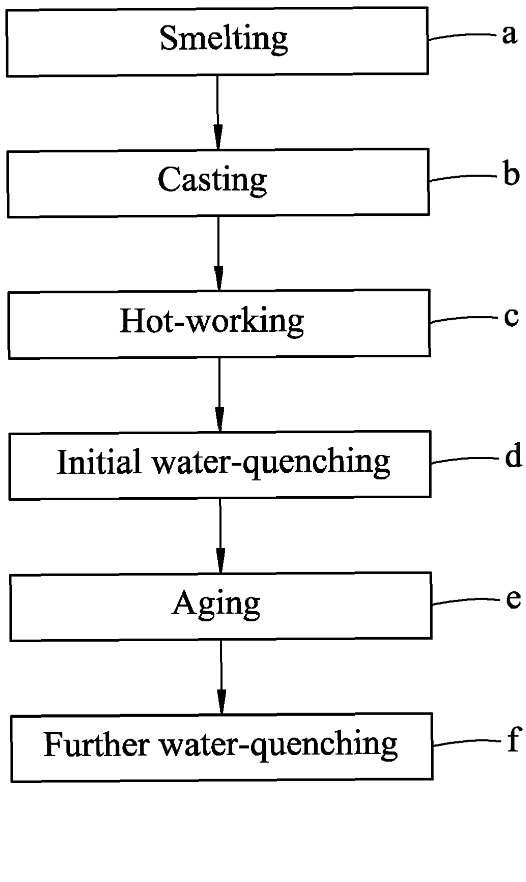

FIG.1

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Description

[0001] The disclosure relates to an austenitic steel alloy, and more particularly to an austenitic steel alloy for hot work tools. The disclosure also relates to a method for making an austenitic steel using the alloy, and an austenitic steel made by the method.

[0002] Martensitic steel is a steel material commonly used for making hot work tools due to its superior mechanical properties such as hardness and toughness. However, since the martensitic steel has a relatively low ductility, the hot work tools made therefrom are liable to cracking.

[0003] AISI H13 steel is an example of the martensitic steel commonly used for making the hot work tools, and includes carbon in an amount of from 0.32 wt% to 0.45 wt%, silicon in an amount of from 0.80 wt% to 1.20 wt%, manganese in an amount of from 0.20 wt% to 0.50 wt%, chromium in an amount of from 4.75 wt% to 5.50 wt%, molybdenum in an amount of from 1.10 wt% to 1.75 wt%, vanadium in an amount of from 0.80 wt% to 1.20 wt%, phosphorus in an amount of not more than 0.03 wt%, sulfur in an amount of not more than 0.03 wt%, and a balance of iron. The AISI H13 steel has a room temperature hardness of from 55 to 58, an elongation at room temperature of from 3% to 5%, an impact toughness of from 5 Joules (J) to 10 J, and a high temperature Rockwell C hardness (HRc) of from 33 to 41. Since the AISI H13 steel having a relatively low elongation is liable to cracking during usage, the room temperature hardness thereof is usually reduced to a range of from 42 to 50 so as to increase the elongation to a range of from 5% to 8%.

[0004] QRO 90 steel is another example of the martensitic steel commonly used for making the hot work tools, and includes carbon in an amount of 0.38 wt%, silicon in an amount of 0.30 wt%, manganese in an amount of 0.75 wt%, chromium in an amount of 2.60 wt%, molybdenum in an amount of 2.25 wt%, vanadium in an amount of 0.9 wt%, and a balance of iron. The QRO 90 steel has a room temperature hardness of 45, an elongation of about 11 %, an impact toughness of 10 J, and a high temperature Rockwell C hardness (HRc) of from 26 to 41.

[0005] Alternatively, austenitic Fe-Mn-Al-C steel has been subjected to extensive researches over the last several decades because of its promising application that is potential associated with high mechanical strength and high ductility.

[0006] Conventional austenitic Fe-Mn-Al-C steel containing carbon in an amount of greater than about 1.2 wt% may be deteriorated in terms of ductility and may be even cracked. Therefore, the amount of carbon in the conventional austenitic Fe-Mn-Al-C steel is usually controlled within a range of from 0.54 wt% to 1.3 wt% and is added with molybdenum (Mo), niobium (Nb), and/or tungsten (W) to enhance the mechanical strength thereof. However, ductility (i.e., elongation) of the conventional austenitic Fe-Mn-Al-C steel may be undesirably reduced due to precipitation of coarse carbides on the grain boundaries of the austenitic Fe-Mn-Al-C steel during an aging treatment. Accordingly, the hot work tools made therefrom are liable to cracking.

[0007] Applicant's U.S. Patent No. 9,528,177 discloses a Fe-Mn-Al-C quarternary alloy which is essentially consisting of Fe, Mn, Al, and C in specific amounts. Specifically, the amount of carbon in the Fe-Mn-Al-C quarternary alloy is controlled within a range of from 1.4 wt% to 2.2 wt%. The Fe-Mn-Al-C quarternary alloy possesses superior ductility and high mechanical strength due to formation of a high density of fine **K**' carbides within an austenite matrix by a spinodal decomposition phase transition mechanism during quenching from a solution heat treatment temperature. It is not recommended to add strong carbide-forming elements such as Cr, Ti, and Mo to the Fe-Mn-Al-C quarternary alloy because addition of such elements appears to have no beneficial effect in the formation of the high density of fine **K**' carbides within the austenite matrix.

[0008] A first object of the disclosure is to provide an austenitic steel alloy which possesses superior mechanical properties without compromising ductility at room temperature, and which also possesses superior mechanical properties at high temperature.

[0009] A second object of the disclosure is to provide a method for making an austenitic steel using the austenitic steel alloy.

[0010] A third object of the disclosure is to provide an austenitic steel made by the method.

[0011] According to a first aspect of the disclosure, there is provided an austenitic steel alloy which comprises manganese in an amount of from 25 wt% to 31 wt%, aluminum in an amount of from 7 wt% to 10 wt%, carbon in an amount of from 1.2 wt% to 1.6 wt%, molybdenum in an amount of more than 0 wt% and less than 6 wt%, and a balance of iron.

[0012] According to a second aspect of the disclosure, there is provided a method for making an austenitic steel using the austenitic steel alloy of the first aspect of the disclosure.

[0013] According to a third aspect of the disclosure, there is provided an austenitic steel made by the method of the second aspect of the disclosure.

[0014] The austenitic steel alloy according to the disclosure possesses superior mechanical properties both at room temperature and at high temperature (e.g., at about 500°C) which are achieved by adding molybdenum in an amount of less than 6 wt% into the austenitic steel alloy including manganese, aluminum, carbon, and iron in specific amounts.

[0015] Other features and advantages of the disclosure will become apparent in the following detailed description of the embodiment (s) with reference to the accompanying drawings, of which:

Figure 1 is a flow diagram of an embodiment of a process for making an austenitic steel according to the disclosure;
Figure 2 is an optical microscope photograph of an austenitic steel of Example 1 after a hot-working treatment;
Figure 3 is an optical microscope photograph of an austenitic steel of Example 3 after a hot-working treatment;
Figure 4 is an optical microscope photograph of an austenitic steel of Example 8 after a hot-working treatment;
Figure 5 is an optical microscope photograph of an austenitic steel of Example 1 after an aging treatment;
Figure 6 is an optical microscope photograph of an austenitic steel of Example 3 after an aging treatment;
Figure 7 is an optical microscope photograph of an austenitic steel of Example 8 after an aging treatment;
Figure 8 is an optical microscope photograph of an austenitic steel of Comparative Example 1 after a hot-working treatment; and
Figure 9 is an optical microscope photograph of an austenitic steel of Comparative Example 2 after a hot-working treatment.

[0016] An austenitic steel alloy according to the disclosure comprises manganese (Mn) in an amount of from 25 wt% to 31 wt%, aluminum (Al) in an amount of from 7 wt% to 10 wt%, carbon (C) in an amount of from 1.2 wt% to 1.6 wt%, molybdenum (Mo) in an amount of more than 0 wt% and less than 6 wt%, and a balance of iron (Fe). The austenitic steel alloy according to the disclosure possesses superior mechanical properties and high ductility, and can be used for making general steel plates such as automobile steel plates, mechanical parts such as gears, hard work tools, and the like.
[0017] Mn is a strong austenite-stabilizing element. An austenite phase is of face-center-cubic (FCC) structure with more dislocation slip systems, and thus possesses better ductility than other crystal structures, such as body-center-cubic (BCC) and hexagonal close packed (HCP) structures. Therefore, in order to obtain a fully austenite structure at room temperature, Mn is in an amount of from 25 wt% to 31 wt% in the austenitic steel alloy according to the disclosure. In certain embodiments, Mn is in an amount of from 26 wt% to 30 wt% . In certain embodiments, Mn is in an amount of from 27 wt% to 29 wt%.
[0018] Al not only is a strong ferrite-stabilizing element, but also is one of the primary elements for forming $(Fe,Mn)_3AlC_x$ carbides (i.e., κ' carbides). Al is in an amount of from 7 wt% to 10 wt% in the austenitic steel alloy according to the disclosure. In certain embodiments, Al is in an amount of from 8 wt% to 10 wt%. In certain embodiments, Al is in an amount of from 8 wt% to 9 wt%.
[0019] C is in an amount of from 1.2 wt% to 1.6 wt% in the austenitic steel alloy according to the disclosure, which is relatively high as compared to the amount (i.e., up to 1.0 wt%) of C in the conventional austenitic Fe-Mn-Al-C steel, in which molybdenum (Mo), niobium (Nb), and/or tungsten (W) is added. In certain embodiments, C is in an amount of from 1.4 wt% to 1.6 wt%.
[0020] Mo is a very strong carbide-forming element. Mo is in an amount of more than 0 wt% and less than 6 wt% in the austenitic steel alloy according to the disclosure. In certain embodiments, Mo is in an amount of from 2 wt% to 6 wt%.
[0021] In certain embodiments, the austenitic steel alloy according to the disclosure further comprises chromium (Cr). Cr is also a very strong carbide-forming element. Cr is in an amount of less than 6 wt% in the austenitic steel alloy according to the disclosure.
[0022] In certain embodiments, the austenitic steel alloy according to the disclosure further comprises cobalt (Co). Co is also a very strong carbide-forming element. Co is in an amount of less than 5 wt% in the austenitic steel alloy according to the disclosure.
[0023] It should be noted that the amounts of low-melting elements (e.g., Mn and Al) in the austenitic steel alloy according to the disclosure may be slightly different from those of the low-melting elements in the austenitic steel made from the alloy due to the smelting that causes evaporation effect of the low-melting elements. However, the difference is within an acceptable tolerance. Therefore, the properties of the austenitic steel made from the alloy will not be affected.
[0024] According to Figure 1, an embodiment of a method for making an austenitic steel according to the disclosure comprises steps of:

a) smelting the austenitic steel alloy according to the disclosure in a high-frequency smelting furnace under an atmosphere to obtain a molten steel alloy;
b) casting the molten steel alloy to obtain a cast piece;
c) subjecting the cast piece to a hot-working treatment such as hot-rolling, hot-forging, and the like at a temperature of from 1100°C to 950°C to obtain a hot-worked body having a predetermined shape;
d) subjecting the hot-worked body to an initial water-quenching treatment followed by cooling to room temperature to obtain a water-quenched body;
e) subjecting the water-quenched body to an aging treatment at a temperature of from 480°C to 600°C to obtain an aged body; and
f) subjecting the aged body to a further water-quenching treatment followed by cooling to room temperature.

[0025] In certain embodiments, in step c), the hot-worked body has a thickness of less than 25% of that of the cast piece.

[0026] In certain embodiments, the temperature for the aging treatment in step e) is from 480°C to 500°C, and the aging treatment is implemented for a period of from 5 hours to 12 hours.

[0027] In certain embodiments, the temperature for the aging treatment in step e) is larger than 500 °C and up to 600°C, and the aging treatment is implemented for a period of from 1 hour to 4 hours.

[0028] The method for making the austenitic steel according to the disclosure is different from the method for making the conventional austenitic Fe-Mn-Al-C steel having a relatively low carbon amount and containing strong carbide-forming elements. Specifically, in the method for making the conventional austenitic Fe-Mn-Al-C steel, a solution heat treatment is required after the hot-working treatment to dissolve the coarse carbides precipitated on the grain boundaries into a matrix phase so as to enhance the ductility of the conventional austenitic Fe-Mn-Al-C steel. In the method for making the austenitic steel according to the disclosure, although the austenitic steel alloy for making the austenitic steel has a relatively high carbon amount and contains strong carbide-forming elements, the temperature for implementing the hot-working treatment is controlled within a range of from 1100°C to 950°C such that the precipitation of the coarse carbides on the grain boundaries during the hot-working treatment can be avoided. Therefore, an austenitic steel having superior mechanical properties and high ductility can be made without the solution heat treatment, which is required in the method for making the conventional austenitic Fe-Mn-Al-C steel.

[0029] It should be noted that instead of implementing the further water-quenching treatment in step f), the aged body can be cooled down naturally to room temperature. In addition, although the solution heat treatment is not a requisite in the method for making the austenitic steel according to the disclosure, it may be optionally implemented, if desired.

[0030] The austenitic steel made by the method according to the disclosure has a fully austenitic phase, a yield strength at 25°C of from 1200 MPa to 1400 MPa, a Rockwell C hardness (HRc) at 25°C of from 45 to 55, an ultimate tensile strength at 25°C of from 1200 MPa to 1500 MPa, and an elongation at 25°C of from 20% to 40%. In addition, the austenitic steel made by the method according to the disclosure has superior yield strength and ultimate tensile strength at high temperature up to 700°C. Therefore, the austenitic steel made by the method according to the disclosure can be used for making general steel plates such as automobile steel plates, mechanical parts such as gears, hard work tools, and the like.

[0031] In certain embodiments, the austenitic steel alloy according to the disclosure comprises carbon in an amount of from 1.42 wt% to 1.5 wt% and molybdenum in an amount of from 3.5 wt% to 5 wt%. The austenitic steel made by the austenitic steel alloy according to the disclosure has an ultimate tensile strength at 25°C of from 1353 MPa to 1386 MPa, a yield strength at 25°C of from 1310 MPa and 1340 MPa, and a HRc at 25°C of from 47 to 47.7.

[0032] In certain embodiments, the austenitic steel alloy according to the disclosure comprises carbon in an amount of from 1.42 wt% to 1.45 wt% and molybdenum in an amount of from 3.5 wt% to 4 wt%. The austenitic steel made by the austenitic steel alloy according to the disclosure has an elongation at 25°C of 25%.

[0033] In certain embodiments, the austenitic steel alloy according to the disclosure comprises manganese in an amount of from 27.7 wt% to 30 wt% and aluminum in an amount of from 8.2 wt% to 8.5 wt%. The austenitic steel made by the austenitic steel alloy according to the disclosure has an ultimate tensile strength at 25°C of from 1280 MPa to 1386 MPa, a yield strength at 25°C of from 1250 MPa and 1350 MPa, a hardness (HRc) at 25°C of from 46.7 to 47.7, and an elongation at 25°C of from 20% to 32%.

[0034] In certain embodiments, the austenitic steel alloy according to the disclosure comprises manganese in an amount of from 27 wt% to 29 wt%, aluminum in an amount of from 8.0 wt% to 8.5 wt%, and molybdenum in an amount of from 3.0 wt% to 6 wt%. The austenitic steel made by the austenitic steel alloy according to the disclosure has an elongation at 25°C of more than 20%, an ultimate tensile strength at 25°C of more than 1280 MPa, a yield strength at 25°C of more than 1230 MPa, an ultimate tensile strength at 300 °C of more than 1000 MPa, and a yield strength at 300 °C of more than 1000 MPa.

[0035] In certain embodiments, the austenitic steel alloy according to the disclosure comprises molybdenum in an amount of 3.0 wt%, and further comprises chromium in an amount of 3 wt% or cobalt in an amount of 2 wt%. The austenitic steel made by the austenitic steel alloy according to the disclosure has an ultimate tensile strength at 25°C of from 1280 MPa to 1344 MPa, a yield strength at 25°C of from 1230 MPa and 1300 MPa, a hardness (HRc) at 25°C of from 45 to 46.8, and an elongation at 25°C of from 24% to 37%.

[0036] Furthermore, the presently available steel for the hot work tools has a density of from 7.8 g/cm^3 to 7.9 g/cm^3. The austenitic steel made by the method according to the disclosure has a density of from 6.6 g/cm^3 to 6.8 g/cm^3, which is 14% less than the density of the presently available steel. Therefore, in addition to superior mechanical properties and high ductility, the austenitic steel made by the method according to the disclosure has a lightweight advantage.

[0037] The conventional Fe-Mn-Al-C alloy having a relatively high amount of carbon of from 1.4 wt% to 2.2 wt% can possess a fully austenitic phase, form a high density of fine κ' carbides (i.e., $(Fe,Mn)_3AlC_x$ carbides) within an austenite matrix, and avoid the precipitation of coarse carbides on the grain boundaries so as to possess superior mechanical strength and high ductility by controlling the hot-working treatment, the solution heat treatment, and the water-quenching treatment. However, in the method for making an austenitic steel according to the disclosure, by adding specific amounts of the strong carbide-forming elements (i.e., Mo and optionally Cr and Co) in the austenitic steel alloy and by controlling the temperature for implementing the hot-working treatment within a specific range (i.e., from 1100°C to 950°C), the precipitation of coarse carbides on the grain boundaries during the hot-working treatment can be avoided. Therefore, an austenitic steel having superior mechanical properties and high ductility can be made without the solution heat treatment which is required in the method for making the conventional austenitic Fe-Mn-Al-C steel.

[0038] Examples of the disclosure will be described hereinafter. It is to be understood that these examples are exemplary and explanatory and should not be cons trued as a limitation to the disclosure.

Example 1:

[0039] A steel alloy containing 30 wt% of Mn, 85 wt% of Al, 1.45 wt% of C, 6 wt% of Mo, and a balance of Fe was smelted in a high-frequency smelting furnace under an atmosphere to obtain a molten steel alloy, followed by casting the molten steel alloy to obtain a cast piece having a thickness of 2 cm.

[0040] The cast piece was heated in a furnace at 1100°C, followed by hot-rolling at a temperature of from 1100°C to 950°C to obtain a test piece having a thickness of less than 25% of that of the cast piece.

[0041] The test piece was subjected to an initial water-quenching treatment followed by cooling to room temperature to obtain a water-quenched body.

[0042] The water-quenched body was polished to remove an oxide layer, followed by an aging treatment at 500°C to obtain an aged body.

[0043] The aged body was subjected to a further water-quenching treatment followed by cooling to room temperature.

Examples 2 to 11:

[0044] In each of Examples 2 to 11, the procedure of Example 1 was repeated using the steel alloy shown in Table 1.

Comparative Examples 1 to 3:

[0045] In each of Comparative Examples 1 to 3, the procedure of Example 1 was repeated using the steel alloy shown in Table 1.

Table 1:

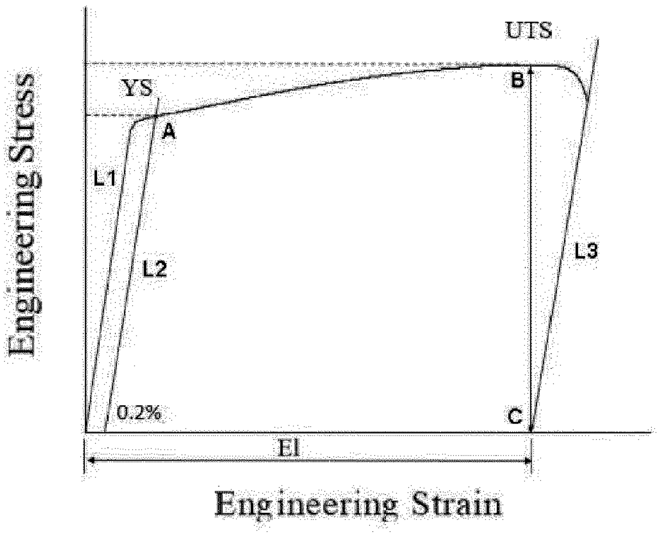
Steel Alloy	Fe (wt%)	Mn (wt%)	Al (wt%)	C (wt%)	Mo (wt%)	Cr (wt%)	Co (wt%)
Ex. 1	balance	30	8.5	1.45	6	-	-
Ex. 2	balance	30	8.5	1.45	4	-	-
Ex. 3	balance	30	8.5	1.50	3.5	-	-
Ex. 4	balance	27	8.5	1.48	6	-	-
Ex. 5	balance	27.5	8.3	1.43	5	-	-
Ex. 6	balance	28	8.2	1.42	3.5	-	-
Ex. 7	balance	28.5	8.4	1.46	2	-	-
Ex. 8	balance	30	8.5	1.45	3	3	-
Ex. 9	balance	28.5	8.0	1.52	3	3	-
Ex. 10	balance	30	8.5	1.45	3	-	2
Ex. 11	balance	27	8.2	1.42	3	-	2
Comp. Ex. 1	balance	28.5	8.2	1.45	9	-	-
Comp. Ex. 2	balance	28	8.3	1.53	9	5	-
Comp. Ex. 3	balance	28.5	8.3	1.5	-	-	-

[0046] Each of the test pieces of Examples 1 to 11 and Comparative Examples 1 to 3 was subjected to yield strength (YS), ultimate tensile strength (UTS), elongation (El), and Rockwell C hardness (HRc) measurements at 25°C according to the procedures described below. The results are shown in Table 2.

[0047] Each of the test pieces of Examples 4, 7, and 9 and Comparative Examples 1 to 3 was subjected to yield strength (YS) and ultimate tensile strength (UTS) measurements at 300°C, 500°C, and 700°C according to the procedures described below. The results are shown in Table 3.

Measurements:

[0048] Each of the test pieces was subjected a tensile test according to the specification of ASTM E8/E8M using an Instron tensile tester at a strain rate of 10^{-3}/sec at a desirable temperature (i.e., 25°C, 300°C, 500°C, or 700°C). For each of the test pieces, a relationship between stress and strain was recorded to obtain a stress-strain curve at the desirable temperature as that shown below.



[0049] L2 and L3 are parallel to L1.

1. Yield Strength (YS):

Yield strength is defined as the stress obtained at 0.2% offset strain in the stress-strain curve, as shown by point A in the stress-strain curve.

2. Ultimate Tensile Strength (UTS):

Ultimate tensile strength is defined as a maximum stress obtained before failure, as shown by point B in the stress-strain curve.

3. Elongation (El):

Elongation is defined as the strain shown by point C in the stress-strain curve.

4. Rockwell C Hardness (HRc)

Rockwell C hardness of each of the test pieces was measured using a Rockwell hardness machine at a load of 150 kgf . A diamond conical indenter was used for the measurement. The results are shown in Table 2.

Table 2

Steel Alloy	YS (MPa)	UTS (MPa)	El (%)	Rockwell C hardness (HRc)	Aging time (500°C/h)
Ex. 1	1350	1375	20	47.4	12
Ex. 2	1340	1366	25	47.0	12
Ex. 3	1330	1386	22	47.7	6
Ex. 4	1230	1308	21	46.3	12
Ex. 5	1320	1365	20	47.4	12
Ex. 6	1310	1353	24	47.0	6
Ex. 7	1250	1314	20	46.5	12

(continued)

Steel Alloy	YS (MPa)	UTS (MPa)	El (%)	Rockwell C hardness (HRc)	Aging time (500°C/h)
Ex. 8	1300	1322	26	45.0	12
Ex. 9	1300	1344	24	46.8	12
Ex. 10	1250	1280	32	46.7	5
Ex. 11	1230	1280	37	46.7	5
Comp. Ex. 1	1400	1464	7	50.2	6
Comp. Ex. 2	1360	1410	5	49.0	5
Comp. Ex. 3	1210	1262	38	45.6	2.5

Table 3:

Steel Alloy	300°C		500°C		700°C	
	YS	UTS	YS	UTS	YS	UTS
Ex. 4	1000	1033	690	758	410	440
Ex. 7	970	1022	650	719	410	449
Ex. 9	1030	1070	700	786	420	444
Comp. Ex. 1	1020	1047	750	827	420	442
Comp. Ex. 2	1010	1068	680	749	400	427
Comp. Ex. 3	850	938	600	670	530	559

[0050] As shown in Table 2, the test pieces of Examples 1 to 11 have a yield strength at 25°C of from 1230 MPa to 1350 MPa, an ultimate tensile strength at 25°C of from 1280 MPa to 1386 MPa, an elongation at 25° of from 20% to 37%, and a Rockwell C hardness (HRc) of from 45.0 to 47.7. It is demonstrated that the test pieces of Examples 1 to 11 have superior mechanical strength and ductility as compared to the test pieces of Comparative Examples 1 and 2. Specifically, the austenitic steel alloy of Examples 1 to 11 has superior mechanical strength and ductility at room temperature (i.e., 25°C) and sufficient mechanical strength at high temperature as well, by controlling the Mo amount in the steel alloy within a range of from 2 wt% to 6 wt% as compared to the steel alloy of Comparative Examples 1 to 3 and conventional AISI H13 and QRO 90 alloys. Therefore, when the austenitic steel alloy according to the disclosure is used to make hot work tools, the cracking problem encountered in the prior art can be avoided.

[0051] In addition, as shown in Table 2, the mechanical strength of each of the test pieces of Examples 1 to 11 is not significantly affected by the aging time of from 5 hours to 12 hours. It is demonstrated that the precipitation of coarse carbides on the grain boundaries of the austenitic steel can be avoided by controlling the temperature during the hot-working treatment. Therefore, the time period for the aging treatment of the austenitic steel alloy according to the disclosure can be more flexible, and the problem of significant precipitation of coarse carbides due to the longer aging time can be alleviated or even avoided.

[0052] Referring to Figures 2 to 4, there is no precipitation of coarse carbides seen in each of the test pieces of Examples 1, 3, and 8 after the hot-working treatment at a temperature of from 1100°C to 950°C. Referring to Figures 5 to 7, there is also no precipitation of coarse carbides seen in each of the test pieces of Examples 1, 3, and 8 after the hot-working treatment at a temperature of from 1100°C to 950°C, followed by the aging treatment. Referring to Figures 8 and 9, however, there is significant precipitation of coarse carbides seen in each of the test pieces of Comparative Examples 1 and 2, in which the strong carbide-forming elements are added in an excess amount.

[0053] Furthermore, as shown in Table 3, the test pieces of Examples 4, 7, and 9 has a yield strength at 300°C of from 970 MPa to 1030 MPa, an ultimate tensile strength at 300°C of from 1022 MPa to 1070 MPa, a yield strength at 500°C of from 650 MPa to 700 MPa, an ultimate tensile strength at 500°C of from 719 MPa to 786 MPa, a yield strength at 700°C of from 410 MPa to 420 MPa, and an ultimate tensile strength at 700°C of from 440 MPa to 449 MPa. Although the test piece of Comparative Example 3 has good ductility at 25°C, the yield strengths and the ultimate tensile strengths at 25°C, 300°C, and 500°C are relatively low as compared to the test pieces of Examples 4, 7, and 9. It is demonstrated that the austenitic steel made by the austenitic steel alloy according to the disclosure has superior mechanical strength both at room temperature (i.e., 25°C) and at high temperature, and thus can be used for making a hot work tools.

[0054] In view of the aforesaid, in a conventional austenitic Fe-Mn-Al-C steel containing carbon in an amount of not more than 1 wt%, the ductility of the austenitic steel made thereby can be improved by adding relatively low amount (s) of the strong carbide-forming element (s) such as molybdenum and/or tungsten. However, the mechanical strength of the austenitic steel cannot be significantly enhanced. On the other hand, in such austenitic Fe-Mn-Al-C steel, the mechanical strength thereof can be improved by adding relatively high amount(s) of the strong carbide-forming element(s). However, the ductility thereof cannot be maintained. In U. S. Patent No. 9,528, 177, it is not recommended to add the strong carbide-forming elements such as Cr, Ti, and Mo to the Fe-Mn-Al-C quarternary alloy because addition of the strong carbide-forming elements appears to have no beneficial effect for forming the high density of fine κ' carbides within the austenite matrix. In the austenitic steel alloy according to the disclosure, molybdenum in a specific amount of less than 6 wt% and carbon in a relatively high amount of from 1.2 wt% to 1.6 wt% are included therein. Therefore, an austenitic steel possessing superior mechanical strength and high ductility both at room temperature and at high temperature can be made using the austenitic steel alloy via a method of this disclosure that includes a hot-working treatment at a temperature of from 1100°C to 950°C.

[0055] In the description above, for the purposes of explanation, numerous specific details have been set forth in order to provide a thorough understanding of the embodiment(s). It will be apparent, however, to one skilled in the art, that one or more other embodiments may be practiced without some of these specific details. It should also be appreciated that reference throughout this specification to "one embodiment," "an embodiment," an embodiment with an indication of an ordinal number and so forth means that a particular feature, structure, or characteristic may be included in the practice of the disclosure. It should be further appreciated that in the description, various features are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of various inventive aspects, and that one or more features or specific details from one embodiment may be practiced together with one or more features or specific details from another embodiment, where appropriate, in the practice of the disclosure.

Claims

1. An austenitic steel alloy **characterized by**:

    manganese in an amount of from 25 wt% to 31 wt%;
    aluminum in an amount of from 7 wt% to 10 wt%;
    carbon in an amount of from 1.2 wt% to 1.6 wt%;
    molybdenum in an amount of more than 0 wt% and less than 6 wt%; and
    a balance of iron.

2. The austenitic steel alloy according to Claim 1, **characterized in that** said manganese is in an amount of from 26 wt% to 30 wt% and said aluminum is in an amount of from 8 wt% to 10 wt%.

3. The austenitic steel alloy according to Claim 2, **characterized in that** said manganese is in an amount of from 27 wt% to 29 wt% and said molybdenum is in an amount of from 2 wt% to 6 wt%.

4. The austenitic steel alloy according to Claim 3, **characterized in that** said aluminum is in an amount of from 8 wt% to 9 wt%.

5. The austenitic steel alloy according to any one of Claims 1 to 4, **characterized in that** said carbon is in an amount of from 1.4 wt% to 1.6 wt%.

6. The austenitic steel alloy according to any one of Claims 1 to 5, **characterized in that** said molybdenum is in an amount of from 2 wt% to 6 wt%.

7. The austenitic steel alloy according to any one of Claims 1 to 6, further **characterized by** chromium in an amount of less than 6 wt%.

8. The austenitic steel alloy according to any one of Claims 1 to 7, further **characterized by** cobalt in an amount of less than 5 wt%.

9. A method for making an austenitic steel, **characterized by** steps of:

a) smelting the austenitic steel alloy of any one of Claims 1 to 8 to obtain a molten steel alloy;
b) casting the molten steel alloy to obtain a cast piece;
c) subjecting the cast piece to a hot-working treatment at a temperature of from 1100°C to 950°C to obtain a hot-worked body;
d) subjecting the hot-worked body to an initial water-quenching treatment to obtain a water-quenched body; and
e) subjecting the water-quenched body to an aging treatment at a temperature of from 480°C to 600°C to obtain an aged body.

10. The method according to Claim 9, **characterized in that** the temperature for the aging treatment is from 480°C to 500°C, and the aging treatment is implemented for a period of from 5 hours to 12 hours.

11. The method according to Claim 9 or 10, **characterized in that** the temperature for the aging treatment is larger than 500°C and up to 600°C, and the aging treatment is implemented for a period of from 1 hour to 4 hours.

12. The method according to any one of Claims 9 to 11, further **characterized by** a step of subjecting the aged body to a further water-quenching treatment.

13. The method according to any one of Claims 9 to 12, **characterized in that** in step c), the hot-worked body has a thickness of less than 25% of that of the cast piece.

14. An austenitic steel made by the method according to any one of Claims 9 to 13, **characterized in that** said austenitic steel has a fully austenitic phase, a yield strength at 25°C of from 1200 MPa to 1400 MPa, a Rockwell C hardness at 25°C of from 45 to 55, an ultimate tensile strength at 25°C of from 1200 MPa to 1500 MPa, and an elongation at 25°C of from 20% to 40%.

15. The austenitic steel according to Claim 14, **characterized in that** said austenitic steel has an ultimate tensile strength at 300°C of larger than 1000 MPa.

16. The austenitic steel according to Claim 14 or 15, **characterized in that** said austenitic steel has a yield strength at 300°C of larger than 970 MPa.

17. The austenitic steel according to any one of Claims 14 to 16, **characterized in that** said austenitic steel has a yield strength at 500°C of larger than 650 MPa and an ultimate tensile strength at 500°C of larger than 700 MPa.

18. The austenitic steel according to any one of Claims 14 to 17, **characterized in that** said austenitic steel has a yield strength at 700°C of from 410 MPa to 420 MPa and an ultimate tensile strength at 700°C of from 440 MPa to 449 MPa.

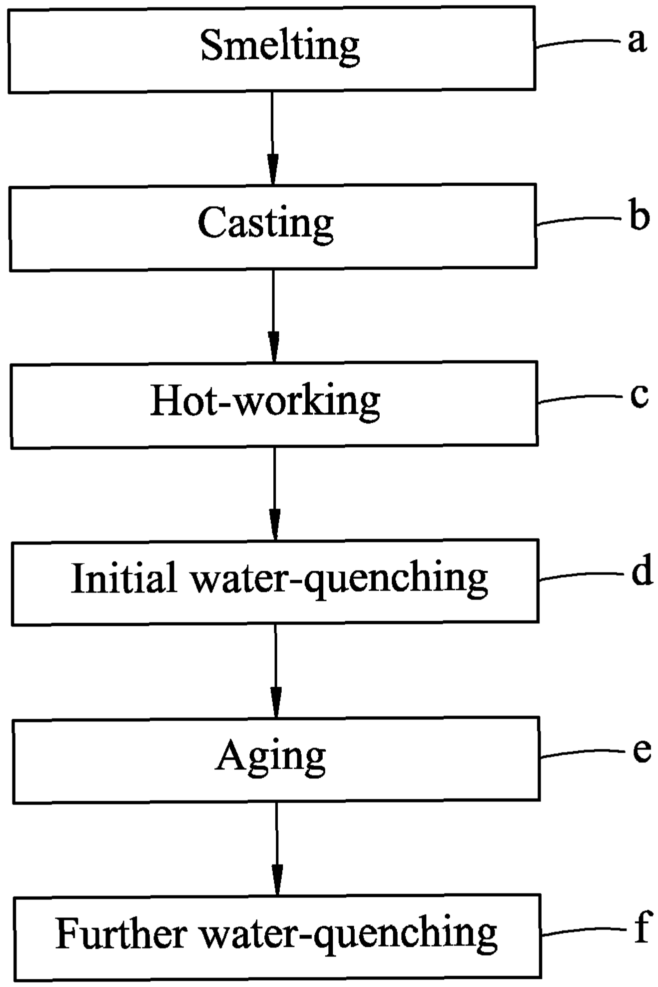

Smelting
a
Casting
b
Hot-working
c
Initial water-quenching
d
Aging
e
Further water-quenching
f

FIG.1

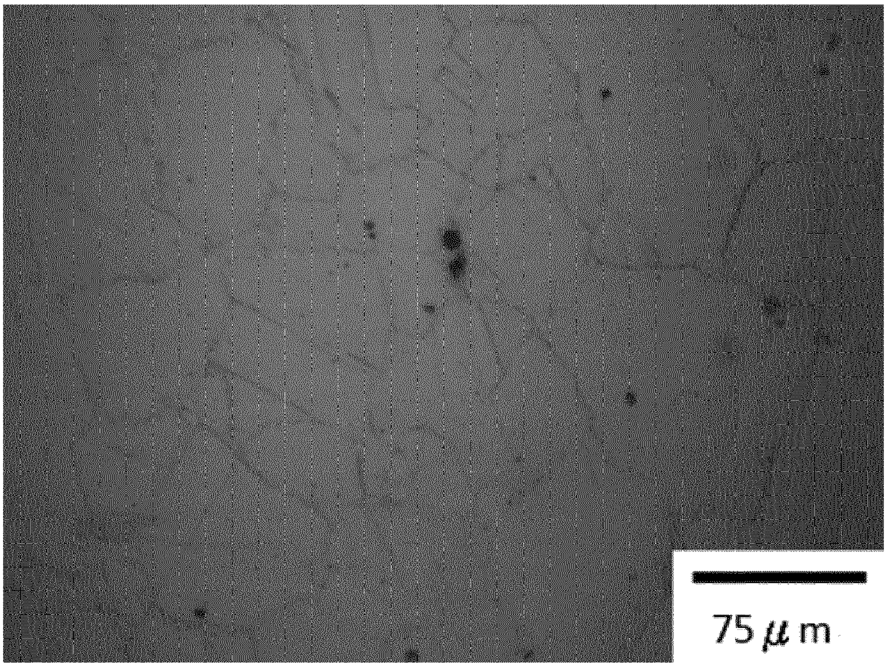


FIG.2

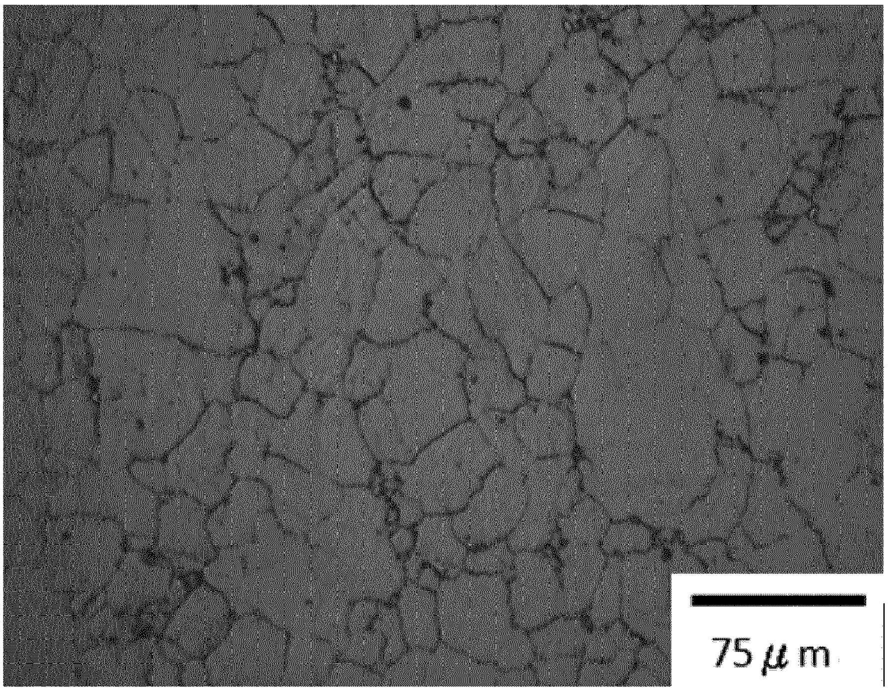


FIG.3

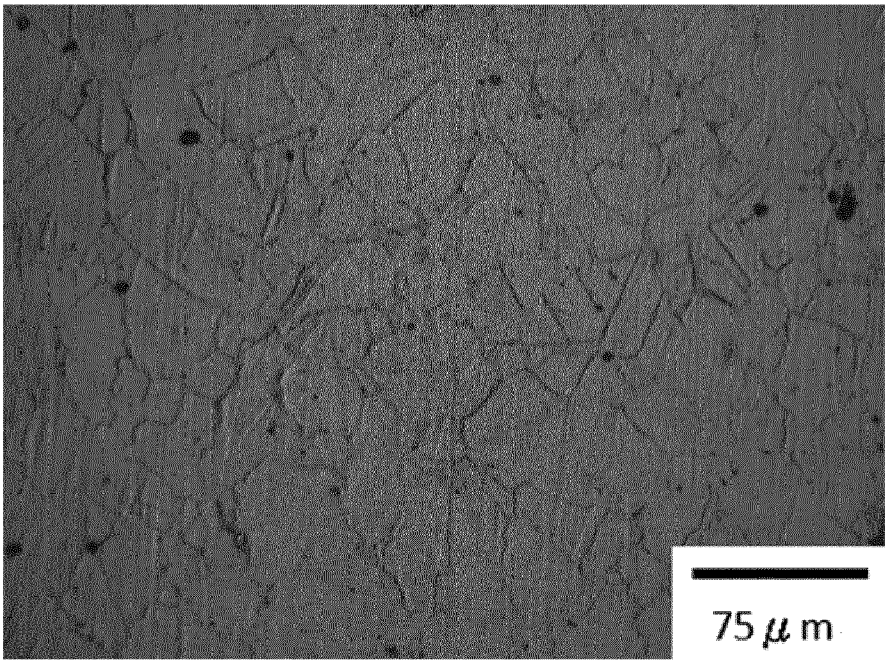


FIG.4

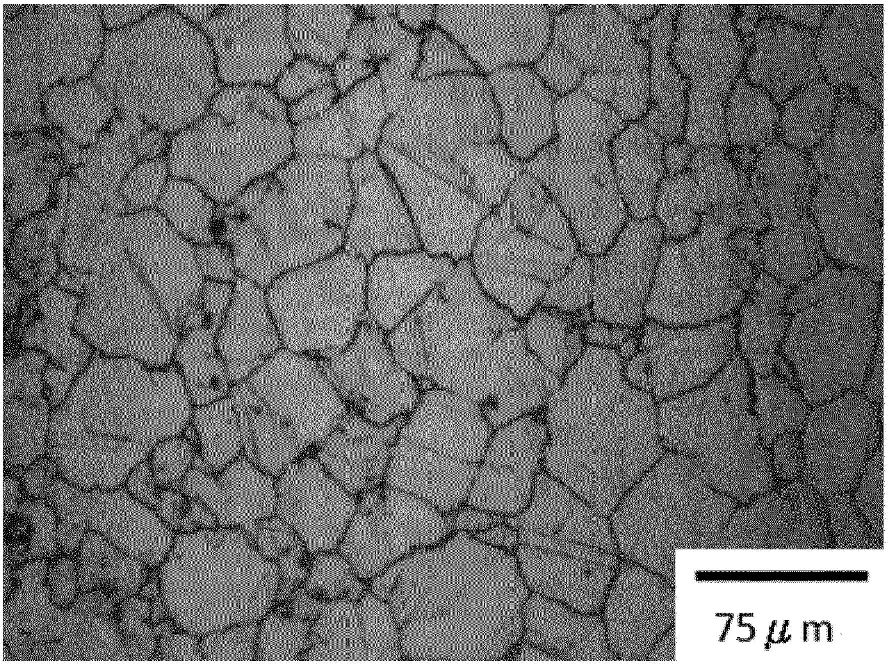


FIG.5

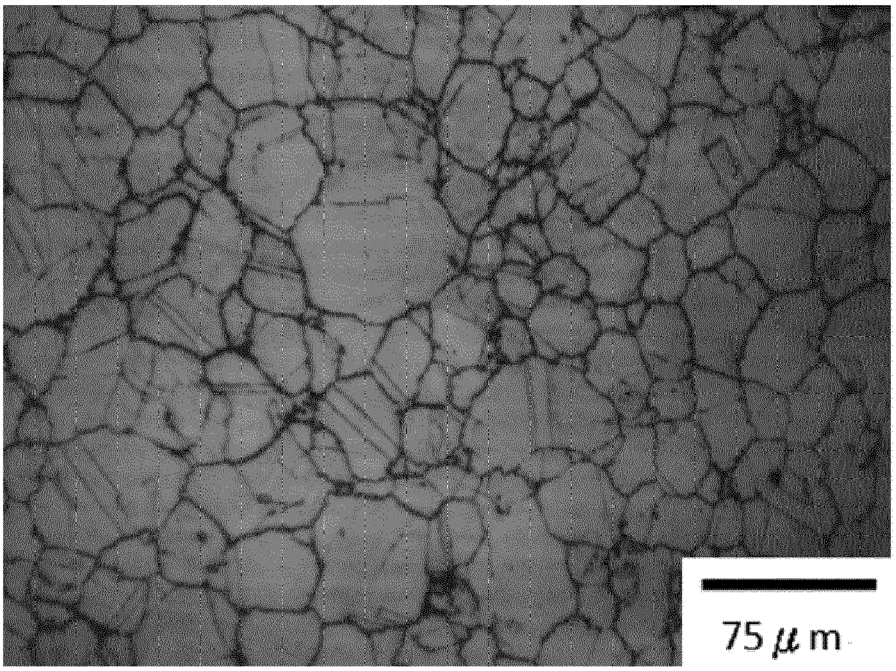


FIG.6

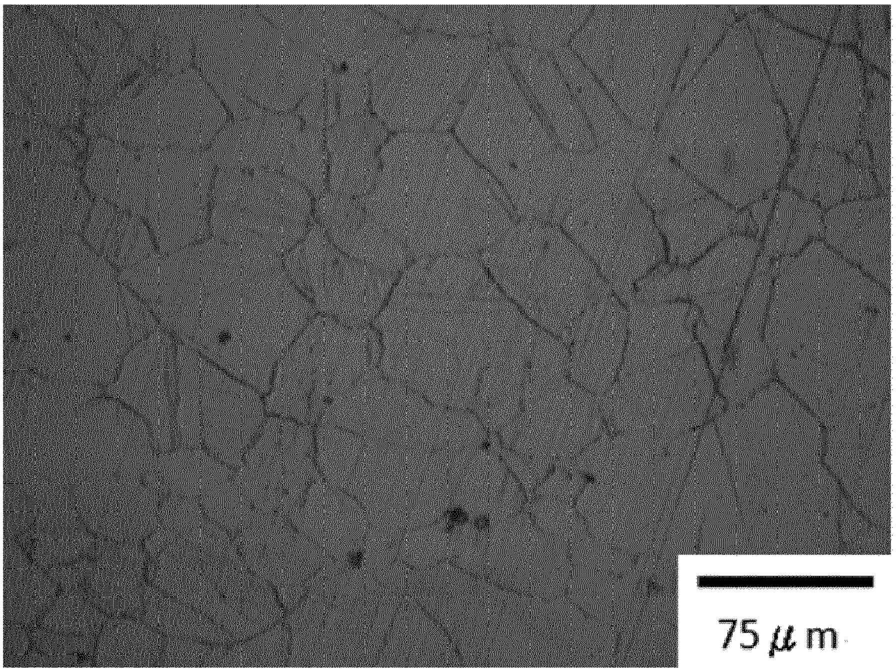


FIG.7

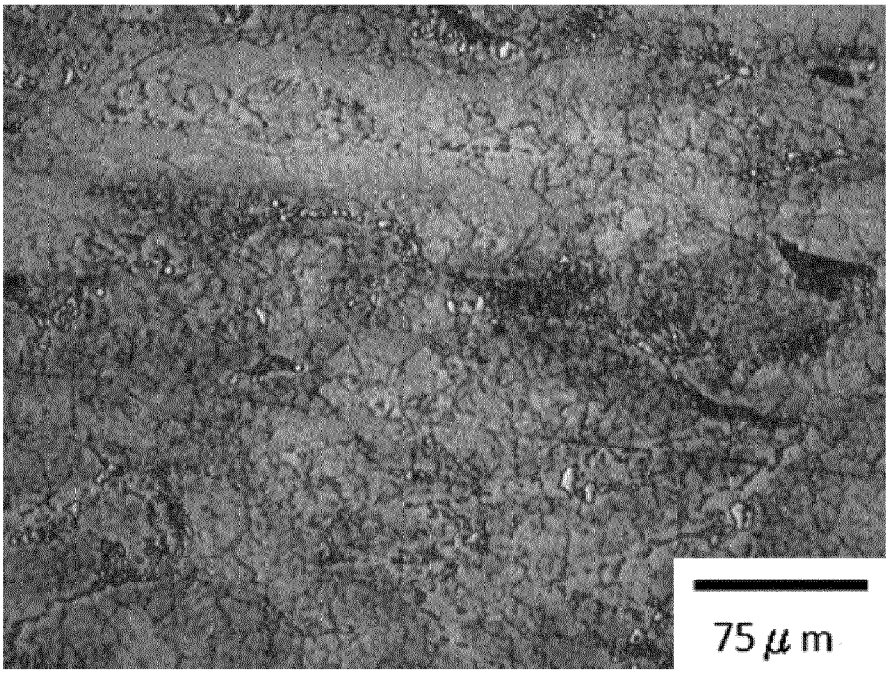


FIG.8

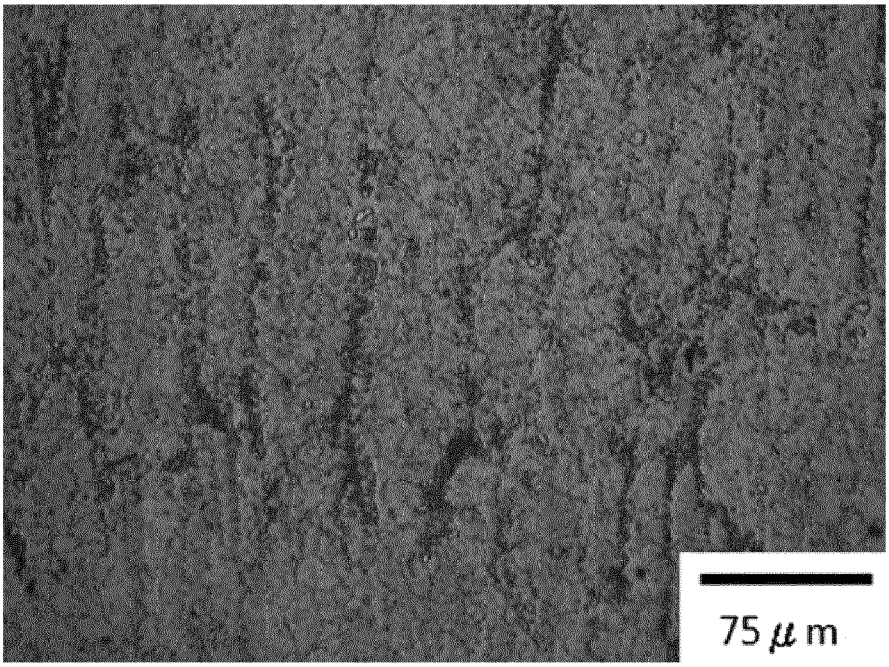


FIG.9

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EUROPEAN SEARCH REPORT

Application Number
EP 18 19 0883

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y A	US 4 975 335 A (WAN CHI-MEEN [US]) 4 December 1990 (1990-12-04) * abstract * * claim 3 *	1-4,7,8 10-13 5,9,14, 18	INV. C22C38/04 C21D6/00 C22C38/00 C22C38/06 C22C38/18 C22C38/22 C22C38/30 C21D9/46
X Y A	DE 12 62 613 B (LANGLEY ALLOYS LTD [GB]) 7 March 1968 (1968-03-07) * abstract * * column 3, line 45 - line 53 * * column 4, line 63 - line 68 * * claim 1 *	1,2,4,5, 7-9 10-13 3,6, 14-18	
X Y A	US 2013/081740 A1 (LIU TZENG-FENG [TW]) 4 April 2013 (2013-04-04) * abstract * * figure 8 * * claims 1-5 *	1,7-9, 14-18 10-13 2-6	
X Y A	FR 2 634 221 A1 (NAT SCIENCE COUNCIL [TW]) 19 January 1990 (1990-01-19) * abstract * * tables 4,7 * * claim 1 *	1,2,4,5, 7,8 10-13 3,6,9, 14-18	TECHNICAL FIELDS SEARCHED (IPC) C22C C21D
X Y A	US 2017/114432 A1 (BUCKHOLZ SAMUEL AUGUST [US]) 27 April 2017 (2017-04-27) * abstract * * claim 1 *	1,2,4,5, 7,8 10-13 3,6,9, 14-18	
X Y A	US 5 167 733 A (HSIEH CHANG-SHENG [TW]) 1 December 1992 (1992-12-01) * abstract * * claim 1 *	1,5,7,8 10-13 2-4,6,9, 14-18	

-/--

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	22 October 2018	Vermeulen, Yves

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Application Number
EP 18 19 0883

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y A	WO 91/03579 A1 (ZIMMER JAMES M [US]) 21 March 1991 (1991-03-21) * abstract * * claim 1 *	1,2,4,5, 7,8 10-13 3,6,9, 14-18	
A	US 2015/075682 A1 (YUGA MASAO [JP] ET AL) 19 March 2015 (2015-03-19) * abstract * * paragraph [0079] - paragraph [0084] * * paragraph [0088] - paragraph [0090] * * claims 1-4 *	1-18	
A	WO 2017/203347 A1 (ARCELORMITTAL [LU]) 30 November 2017 (2017-11-30) * abstract * * claim 1 *	1-18	
A	US 4 944 814 A (ZIMMER JAMES M [US] ET AL) 31 July 1990 (1990-07-31) * abstract * * table 1 * * claim 1 *	1-18	TECHNICAL FIELDS SEARCHED (IPC)
A	US 2014/007992 A1 (BALICHEV EVGENY [DE] ET AL) 9 January 2014 (2014-01-09) * abstract * * claims 1,2,8 *	1-18	
A	JP H02 228450 A (TOKUSHU DENKYOKU KK) 11 September 1990 (1990-09-11) * abstract *	1-18	
A	US 4 865 662 A (ZIMMER JAMES M [US] ET AL) 12 September 1989 (1989-09-12) * abstract * -/--	1-18	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	22 October 2018	Vermeulen, Yves

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& : member of the same patent family, corresponding document

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Application Number
EP 18 19 0883

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	GB 2 220 674 A (NAT SCIENCE COUNCIL [TW]) 17 January 1990 (1990-01-17) * abstract * * claim 1 * -----	1-18	
A	US 8 313 592 B2 (CAO WEI-DI [US]; MCDEVITT ERIN T [US]; ATI PROPERTIES INC [US]) 20 November 2012 (2012-11-20) * abstract * -----	1-18	

TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	22 October 2018	Vermeulen, Yves

CATEGORY OF CITED DOCUMENTS

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22-10-2018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4975335 A	04-12-1990	AT 114737 T	15-12-1994
		AU 619336 B2	23-01-1992
		CA 1336550 C	08-08-1995
		DE 68919693 D1	12-01-1995
		EP 0411061 A1	06-02-1991
		JP H03500306 A	24-01-1991
		US 4975335 A	04-12-1990
		WO 9000630 A1	25-01-1990
DE 1262613 B	07-03-1968	DE 1262613 B	07-03-1968
		GB 841366 A	13-07-1960
US 2013081740 A1	04-04-2013	CN 103031487 A	10-04-2013
		TW 201313923 A	01-04-2013
		US 2013081740 A1	04-04-2013
		US 2017107588 A1	20-04-2017
FR 2634221 A1	19-01-1990	FR 2634221 A1	19-01-1990
		JP H02247356 A	03-10-1990
US 2017114432 A1	27-04-2017	US 2017114432 A1	27-04-2017
		WO 2017070273 A1	27-04-2017
US 5167733 A	01-12-1992	NONE	
WO 9103579 A1	21-03-1991	BR 8907902 A	01-09-1992
		JP H05504789 A	22-07-1993
		WO 9103579 A1	21-03-1991
US 2015075682 A1	19-03-2015	CN 104105810 A	15-10-2014
		EP 2813596 A1	17-12-2014
		JP 5177310 B2	03-04-2013
		JP 2012184500 A	27-09-2012
		KR 20140117560 A	07-10-2014
		KR 20160090399 A	29-07-2016
		SG 11201403786T A	27-11-2014
		US 2015075682 A1	19-03-2015
		WO 2013118313 A1	15-08-2013
WO 2017203347 A1	30-11-2017	WO 2017203312 A1	30-11-2017
		WO 2017203347 A1	30-11-2017
US 4944814 A	31-07-1990	CA 1334802 C	21-03-1995
		US 4944814 A	31-07-1990
US 2014007992 A1	09-01-2014	BR 112013017753 A2	11-10-2016

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 18 19 0883

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The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

22-10-2018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		CA 2823095 A1	19-07-2012
		CN 103328120 A	25-09-2013
		DE 102011000089 A1	12-07-2012
		EP 2663411 A1	20-11-2013
		ES 2625281 T3	19-07-2017
		JP 2014505172 A	27-02-2014
		KR 20130100215 A	09-09-2013
		MX 345374 B	26-01-2017
		RU 2013137456 A	20-02-2015
		US 2014007992 A1	09-01-2014
		WO 2012095232 A1	19-07-2012
JP H02228450 A	11-09-1990	NONE	
US 4865662 A	12-09-1989	AU 639673 B2	05-08-1993
		BR 8907901 A	01-09-1992
		CA 1336141 C	04-07-1995
		DE 68923711 D1	07-09-1995
		DE 68923711 T2	18-04-1996
		EP 0414949 A1	06-03-1991
		EP 0489727 A1	17-06-1992
		JP 3076814 B2	14-08-2000
		JP H05504788 A	22-07-1993
		US 4865662 A	12-09-1989
		WO 9103580 A1	21-03-1991
GB 2220674 A	17-01-1990	NONE	
US 8313592 B2	20-11-2012	AU 2009277046 A1	04-02-2010
		EP 2313532 A1	27-04-2011
		JP 5976317 B2	23-08-2016
		JP 6113111 B2	12-04-2017
		JP 2011529533 A	08-12-2011
		JP 2014208911 A	06-11-2014
		US 2010018615 A1	28-01-2010
		US 2011186190 A1	04-08-2011
		WO 2010014269 A1	04-02-2010

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 9528177 B **[0007]**
- US 9528177 A **[0054]**