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(54) Title: BEARING STEEL

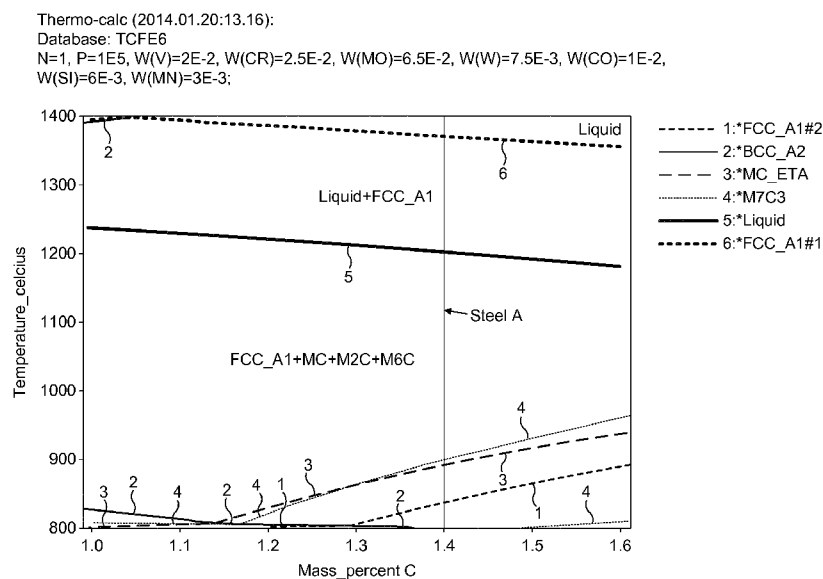


FIG. 1

(57) Abstract: A steel alloy for a bearing, the alloy having a composition comprising: from 1.1 to 1.6 wt.% carbon, from 0.1 to 1.5 wt.% silicon, from 0.1 to 1.0 wt.% manganese, from 2.0 to 6.0 wt.% chromium, from 1.0 to 10.0 wt.% molybdenum, from 0.5 to 3.0 wt.% tungsten, from 0.5 to 5.0 wt.% vanadium, from 0 to 5.0 wt.% cobalt, from 0 to 0.3 wt.% copper, from 0 to 0.25 wt.% nickel, from 0 to 0.05 wt.% aluminium, from 0 to 0.1 wt.% niobium, from 0 to 0.2 wt.% tantalum, up to 150 ppm nitrogen, up to 30 ppm titanium, the balance iron, together with any unavoidable impurities.

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Bearing Steel

Technical Field

- 5 The present invention relates generally to the field of metallurgy and to a steel alloy composition for use in bearing applications. The steel alloy composition may be ingot cast.

Background

- 10 Bearings are devices that permit constrained relative motion between two parts. Rolling element bearings comprise inner and outer raceways and a plurality of rolling elements (balls or rollers) disposed there-between. For long-term reliability and performance, it is important that the various elements have high hardness and resistance to rolling contact fatigue, wear and creep.

- 15 A known bearing steel comprises 0.97 wt.% C, 0.32 wt.% Si, 0.31 wt.% Mn, 1.43 wt.% Cr, the balance being Fe and any unavoidable impurities. Another commercial through-hardenable steel comprises 0.65 wt.% C, 1.50 wt.% Si, 1.40 wt.% Mn, 1.10 wt.% Cr, 0.25 wt.% Mo, the balance being Fe and any unavoidable impurities.

- 20 Many bearing components are produced by a powder metallurgical process, optionally together with hot isostatic pressing (HIP). Sometime it can be more economical to use ingot casting instead of powder metallurgy/HIP. However, segregation can occur during ingot casting and this is detrimental to the final mechanical properties of the bearing component,
- 25 for example resistance to rolling contact fatigue.

The present invention aims to provide a bearing steel which can be ingot cast and which does not suffer unduly from segregation effects during processing. In particular, the present invention provides a steel alloy for a bearing, the alloy having a composition comprising:

- 30 from 1.1 to 1.6 wt.% carbon,
from 0.1 to 1.5 wt.% silicon,
from 0.1 to 1.0 wt.% manganese,
from 2.0 to 6.0 wt.% chromium,
35 from 1.0 to 10.0 wt.% molybdenum,

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from 0.5 to 3.0 wt.% tungsten,
from 0.5 to 5.0 wt.% vanadium,

from 0 to 5.0 wt.% cobalt,
from 0 to 0.3 wt.% copper,
from 0 to 0.25 wt.% nickel,
from 0 to 0.05 wt.% aluminium,

from 0 to 0.1 wt.% niobium,
from 0 to 0.2 wt.% tantalum,

up to 150 ppm nitrogen,
up to 30 ppm titanium,

the balance iron, together with any unavoidable impurities.

The present invention will now be described further. In the following passages different aspects of the invention are defined in more detail. Each aspect so defined may be combined with any other aspect or aspects unless clearly indicated to the contrary. In particular, any feature indicated as being preferred or advantageous may be combined with any other feature or features indicated as being preferred or advantageous.

In the present invention, the steel alloy composition comprises from 1.1 to 1.6 wt.% carbon, preferably from 1.2 to 1.5 wt.% carbon, more preferably from 1.3 to 1.4 wt.% carbon wt.% carbon. In combination with the other alloying elements, this results in the desired martensitic and/or bainitic microstructure, together with one or more carbides, nitrides and/or carbonitrides. The relatively high carbon content impacts positively on mechanical properties, for example hardness, of bearing components formed from the alloy. In particular, the alloy may exhibit a hardness of at least 66 HRC.

The alloy composition according to the present invention lends itself to ingot casting, and the resulting bearing steel exhibits a high fraction of relatively fine carbides (and optionally carbonitrides and nitrides). This, in turn, has been found to be beneficial in terms of hardness and resistance to rolling contact fatigue, which are important properties in bearing applications. The carbides present in the final microstructure typically include, for example,

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MC, M_6C , M_2C or M_7C_3 . These carbides typically contain one or more of Fe, Cr, Mo, W, Mn and V.

5 With a relatively high carbon content, the overall percentage of carbides (and optional nitrides and carbonitrides), which are retained during hardening is quite high. This impedes austenite grain growth, which is beneficial since such grain growth can be detrimental to mechanical properties and fatigue.

10 The steel alloy composition comprises from 0.1 to 1.5 wt.% silicon, preferably from 0.2 to 1.0 wt.% silicon, more preferably from 0.3 to 0.8 wt.% silicon, still more preferably from 0.4 to 0.6 wt.% silicon. In combination with the other alloying elements, this results in the desired microstructure with a minimum amount of retained austenite. Silicon also helps to suppress undue precipitation of cementite. Also, silicon strengthens the structure and improves resistance to softening caused by tempering. However, too high a silicon content may result
15 in undesirable surface oxides and a poor surface finish. For this reason, the maximum silicon content is 1.5 wt.%.

The steel alloy composition comprises from 0.1 to 1.0 wt.% manganese, preferably from 0.1 to 0.6 wt.% manganese, more preferably from 0.1 to 0.5 wt.% manganese, still more
20 preferably from 0.2 to 0.4 wt.% manganese. Manganese acts to increase the stability of austenite relative to ferrite. Manganese also acts to improve hardenability. Manganese may also act to lower the stacking fault energy of the austenite.

The steel composition comprises from 2.0 to 6.0 wt.% chromium. Apart from its positive
25 effect on hardenability, the content of chromium was found during thermodynamic calculations to greatly impact the type of carbide obtainable during hardening in that if the concentration is too low, the undesirable cementite phase is stabilised. The alloy therefore comprises at least 2.0 wt.% chromium. On the other hand, the chromium content must be restricted, for example, to ensure sufficient carbon in solid solution in the austenite phase
30 during hardening. For the austenite to transform into a sufficiently hard structure at lower temperatures it must possess sufficient dissolved carbon and optionally nitrogen. The steel alloy therefore comprises a maximum of 6.0 wt.% chromium. The steel composition preferably comprises from 2.2 to 5.8 wt.% chromium, more preferably from 2.4 to 5.6 wt.% chromium, still more preferably from 2.5 to 5.5 wt.% chromium.

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The steel composition comprises from 1.0 to 10.0 wt.% molybdenum, preferably from 4.0 to 10.0 wt.% molybdenum, more preferably from 5.0 to 8.0 wt.% molybdenum, still more preferably from 6.0 to 7.0 wt.% molybdenum. Molybdenum may act to avoid grain boundary embrittlement. However, molybdenum is expensive and hence it is desirable, if possible, to limit its content in the alloy. In combination with the other alloying elements, it is possible to limit the molybdenum content to a maximum of 10 wt.%, preferably a maximum of 7.0 wt.%.
5

The steel composition comprises from 0.5 to 3.0 wt.% tungsten, preferably from 0.5 to 2.0 wt.% tungsten, more preferably from 0.6 to 1.7 wt.% tungsten, still more preferably from 0.75 to 1.5 wt.% tungsten. The presence of tungsten in these amounts in the steel composition has been found to be beneficial in controlling carbide coarsening during tempering. Tungsten may therefore act, in this respect, in a similar way to molybdenum.
10

The steel composition comprises from 0.5 to 5.0 wt.% vanadium, preferably from 1.0 to 5.0 wt.% vanadium, more preferably from 1.5 to 4.5 wt.% vanadium, still more preferably from 2.0 to 4.0 wt.% vanadium. Vanadium forms carbides (and optionally nitrides and/or carbonitrides), which is important to achieve good hardness for bearing applications. Also, the vanadium in these amounts prevents any possible excessive austenite grain growth during hardening.
15

Cobalt is an optional alloying element but its presence can be beneficial in terms of carbide refinement. For this reason, the alloy may comprise up to 5.0 wt.% cobalt, for example 0.05 to 1.0 wt.% cobalt.
20

In some embodiments, nitrogen may be added such that the steel alloy comprises from 50 to 150 ppm nitrogen, preferably from 75 to 100 ppm nitrogen. The presence of nitrogen may be beneficial for promoting the formation of complex regular M₂C carbides during ingot casting. The complex regular M₂C carbides can be easily broken up during, for example, hot working, so this can be beneficial. In other embodiments, there is no deliberate addition of nitrogen. Nevertheless, the alloy may necessarily still comprise at up to least 50 ppm nitrogen due to exposure to the atmosphere during melting.
25
30

Preferably, the steel alloy comprises no more than 0.05 wt.% aluminium. More preferably, the steel alloy is free of aluminium. The presence of aluminium may be undesirable, as nitrogen (if present) can be lost due to the formation of aluminium nitrides.
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As noted above, the steel composition may also optionally include one or more of the following elements:

- 5 from 0 to 0.25 wt.% nickel (for example 0.02 to 0.2 wt.% nickel)
- from 0 to 0.3 wt.% copper (for example 0.02 to 0.2 wt.% copper)
- from 0 to 5.0 wt.% cobalt (for example 0.05 to 1.0 wt.% cobalt)
- from 0 to 0.05 wt.% aluminium (for example 0.02 wt.% aluminium to 0.04 wt.% aluminium)
- from 0 to 0.1 wt.% niobium (for example 0.025 to 0.05 wt.% niobium)
- 10 from 0 to 0.2 wt.% tantalum (for example 0.025 to 0.1 wt.% tantalum)
- from 0 to 150 ppm nitrogen (for example 50 to 150 ppm nitrogen)

It will be appreciated that the steel alloy referred to herein may contain unavoidable impurities, although, in total, these are unlikely to exceed 0.3 wt.% of the composition.

- 15 Preferably, the alloys contain unavoidable impurities in an amount of not more than 0.1 wt.% of the composition, more preferably not more than 0.05 wt.% of the composition. In particular, the steel composition may also include one or more impurity elements. A non-exhaustive list of impurities includes, for example:

- 20 from 0 to 0.025 wt.% phosphorous
- from 0 to 0.015 wt.% sulphur
- from 0 to 0.04 wt.% arsenic
- from 0 to 0.075 wt.% tin
- from 0 to 0.075 wt.% antimony
- 25 from 0 to 0.002 wt.% lead
- from 0 to 0.002 wt.% boron

The steel alloy composition preferably comprises little or no sulphur, for example from 0 to 0.015 wt.% sulphur.

30

The steel alloy composition preferably comprises little or no phosphorous, for example from 0 to 0.025 wt.% phosphorous.

- 35 The steel composition preferably comprises ≤ 15 ppm oxygen. Oxygen may be present as an impurity. The steel composition preferably comprises ≤ 30 ppm titanium. Titanium may

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be present as an impurity. The steel composition preferably comprises ≤ 20 ppm boron. The steel composition preferably comprises ≤ 50 ppm calcium. Calcium may be present as an impurity.

- 5 The steel alloy composition may consist essentially of the recited elements. It will therefore be appreciated that in addition to those elements that are mandatory other non-specified elements may be present in the composition provided that the essential characteristics of the composition are not materially affected by their presence.
- 10 The steel alloy according to the present invention lends itself to ingot casting processes. The alloy composition has been found to reduce segregation during casting, which results in better uniformity and fineness in the steel structure. This, in turn, leads to better resistance to rolling contact fatigue. Further refinement of the microstructure may be achieved via additional processing such as vacuum arc remelting (VAR) and/or vacuum induction melting
- 15 (VIM-VAR) the steel alloy the steel alloy.

The steel alloy according to the present invention preferably has a microstructure comprising a tempered martensite and/or bainitic matrix together with one or more carbides, nitrides and/or carbonitrides. In particular, the microstructure preferably exhibits a high fraction of

20 fine carbides specifically for optimum performance in demanding bearing applications. The microstructure may contain a small amount of retained austenite.

According to another aspect of the present invention there is provided a bearing component, comprising a steel alloy as herein described. Examples of bearing components where the

25 steel can be used include a rolling element (e.g. ball, cylinder or tapered rolling element), an inner ring, and an outer ring. The present invention also provides a bearing comprising a bearing component as herein described. A potential application for the steel alloy according to the invention is in a marine pod bearing. Such an application typically has to withstand a load of approximately 1200 MPa.

30

According to yet another aspect of the present invention there is provided a method of manufacturing a steel alloy comprising:

- (i) providing a steel alloy as herein described; and
- (ii) ingot casting the steel alloy.

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The method may further comprise one or both of the following further steps:

- (iii) vacuum arc remelting the steel alloy; and/or
- (iv) vacuum induction melting the steel alloy.

- 5 The present invention will now be described further with reference to a suitable heat treatment for the steel alloy, provided by way of example.

Hardening

- 10 · Components should preferably be cleaned of oils, moisture or other contaminants prior to loading in the vacuum furnace.
- The temperature of the furnace will not normally exceed approximately 250°C when the discs are placed in it.
- Heat under vacuum to about 600±5 °C at 10 to 15 °C/min and equalise.
- 15 · After attaining about 600±5 °C, heat to about 750±5 °C (+/- 5 °C) at 10 to 15 °C/min and equalise.
- Heat to approximately 1000-1150 °C at 5 to 10 °C/min and soak for about 20 to 30 minutes.
- After austenitisation, an austenitic matrix is obtained. Approximately 10 vol.% of
- 20 molybdenum-rich M₂C, vanadium-rich MC and possibly chromium-rich M₆C are not dissolved.

Gas Quenching

- 25 · Gas quench with nitrogen gas at about 6 to 8 bar.
- Transfer time to the quench chamber should be kept to a minimum.
- Cool down to about 40-50°C.
- The expected microstructure includes the undissolved carbides (MC, M₂C and M₆C), a martensitic matrix, and retained austenite.

30

Triple Tempering

- Temper at approximately 500-600°C for at least about 1 hour in vacuum or protective atmosphere.
- 35 · Rinse with cold water at about 10°C for about 10 minutes.

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- Temper at approximately 500-600°C for at least about 1 hour in vacuum or protective atmosphere.
- Rinse with cold water at about 10°C for about 10 minutes.
- Temper at approximately 500-600°C for at least about 1 hour in vacuum or protective atmosphere.
- A sub-zero soak at about -70 °C can be used between the tempering steps to reduce the retained austenite content.
- The expected microstructure contains undissolved carbides (MC, M₂C and M₆C), a tempered martensitic matrix, retained austenite and very fine secondary carbides.

The steel alloys according to the present invention are intended to be ingot cast. This means that reducing segregation during steel making is important. Reducing segregation leads to a better uniformity and fineness in the steel structure, which in turn leads to better resistance to rolling contact fatigue. In order to reduce segregation during ingot casting, the concentration of carbon, vanadium, chromium and molybdenum in the steel alloy according to the present invention are balanced to avoid or hinder the formation of delta-ferrite, and at the same time to promote the formation of M₂C carbides during solidification. The metastable M₂C carbides may decompose into MC and M₆C carbides in the following homogenisation and hot working processes. With this decomposition, it is easier to break up and separate large M₂C carbides during forging or hot rolling.

Further refinement of the microstructure may be achieved via additional processing such as vacuum arc remelting (VAR) and/or vacuum induction melting (VIM-VAR) the steel alloy the steel alloy.

The target microstructure is tempered martensite or bainitic matrix, together with metal carbides and optionally nitrides and/or carbonitrides. The steel will typically have a high fraction of hard and fine carbides such as MC, M₆C, M₂C or M₇C₃. These carbides typically contain one or more of Fe, Cr, Mo, W, Mn and V.

The composition and microstructure result in good mechanical properties for bearing applications. For example, a hardness of at least 66 HRC can be achieved.

Examples

5 The present invention will now be described further with reference to the following non-limiting examples. In particular, the following are examples of the inventive steel alloy composition:

Steel A

Fe-1.4C-2.0V-2.5Cr-6.5Mo-0.75W-1.0Co-0.6Si-0.3Mn (wt.%)

10 Together with any unavoidable impurities.

Steel B

Fe-1.5C-4.0V-5.5Cr-7.0Mo-1.5W-1.0Co-0.4Si-0.3Mn (wt.%)

Together with any unavoidable impurities.

15

Steel C

Fe-1.2C-2.0V-4.5Cr-7.0Mo-1.5W-1.0Co-0.4Si-0.3Mn (wt.%)

Together with any unavoidable impurities.

20 Figure 1 shows the calculated equilibrium phase diagram for Steel A with 1.4 wt.% C.

The foregoing detailed description has been provided by way of explanation and illustration, and is not intended to limit the scope of the appended claims. Many variations in the presently preferred embodiments illustrated herein will be apparent to one of ordinary skill in
25 the art, and remain within the scope of the appended claims and their equivalents.

CLAIMS:

1. A steel alloy for a bearing, the alloy having a composition comprising:

5 from 1.1 to 1.6 wt.% carbon,
from 0.1 to 1.5 wt.% silicon,
from 0.1 to 1.0 wt.% manganese,
from 2.0 to 6.0 wt.% chromium,
from 1.0 to 10.0 wt.% molybdenum,
10 from 0.5 to 3.0 wt.% tungsten,
from 0.5 to 5.0 wt.% vanadium,

from 0 to 5.0 wt.% cobalt,
from 0 to 0.3 wt.% copper,
15 from 0 to 0.25 wt.% nickel,
from 0 to 0.05 wt.% aluminium,

from 0 to 0.1 wt.% niobium,
from 0 to 0.2 wt.% tantalum,

20 up to 150 ppm nitrogen,
up to 30 ppm titanium,

the balance iron, together with any unavoidable impurities.

25

2. The steel alloy of claim 1, comprising from 1.2 to 1.5 wt.% carbon, more preferably from 1.3 to 1.4 wt.% carbon.

3. The steel alloy of claim 1 or claim 2, comprising from 0.2 to 1.0 wt.% silicon, more
30 preferably from 0.3 to 0.8 wt.% silicon, still more preferably from 0.4 to 0.6 wt.% silicon.

4. The steel alloy of any one of the preceding claims, comprising from 0.1 to 0.6 wt.%
manganese, more preferably from 0.1 to 0.5 wt.% manganese, still more preferably from 0.2
to 0.4 wt.% manganese.

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5. The steel alloy of any one of the preceding claims, comprising from 2.2 to 5.8 wt.% chromium, more preferably from 2.4 to 5.6 wt.% chromium, still more preferably from 2.5 to 5.5 wt.% chromium.
- 5 6. The steel alloy of any one of the preceding claims, comprising from 4.0 to 10.0 wt.% molybdenum, more preferably 5.0 to 8.0 wt.% molybdenum, still more preferably 6.0 to 7.0 wt.% molybdenum
7. The steel alloy of any one of the preceding claims, comprising from 1.0 to 5.0 wt.%
10 vanadium, more preferably from 1.5 to 4.5 wt.% vanadium, more preferably from 2.0 to 4.0 wt.% vanadium.
8. The steel alloy of any one of the preceding claims, comprising from 0.5 to 2.0 wt.% tungsten, more preferably from 0.6 to 1.7 wt.% tungsten, more preferably from 0.75 to 1.5
15 wt.% tungsten.
9. The steel alloy of any one of the preceding claims, comprising from 50 to 150 ppm nitrogen, preferably from 75 to 125 ppm nitrogen.
- 20 10. The steel alloy of any one of the preceding claims wherein the alloy has a microstructure comprising martensite and/or bainite and one or more carbides, nitrides and/or carbonitrides.
11. A bearing component made from the steel alloy of any preceding claim.
25
12. A bearing component as claimed in claim 11 which is a rolling element, inner ring or outer ring for a bearing.
13. A bearing comprising a bearing component as claimed in claim 11 or claim 12.
30
14. A method of manufacturing a steel alloy comprising:
(i) providing a steel alloy as defined in any one of the preceding claims; and
(ii) ingot casting the steel alloy.

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15. A method as claimed in claim 14, further comprising one or both of the following further steps:

- (iii) vacuum arc remelting the steel alloy; and/or
- (iv) vacuum induction melting the steel alloy.

Thermo-calc (2014.01.20:13.16):
Database: TCFe6
N=1, P=1E5, W(V)=2E-2, W(CR)=2.5E-2, W(MO)=6.5E-2, W(W)=7.5E-3, W(CO)=1E-2,
W(SI)=6E-3, W(MN)=3E-3;

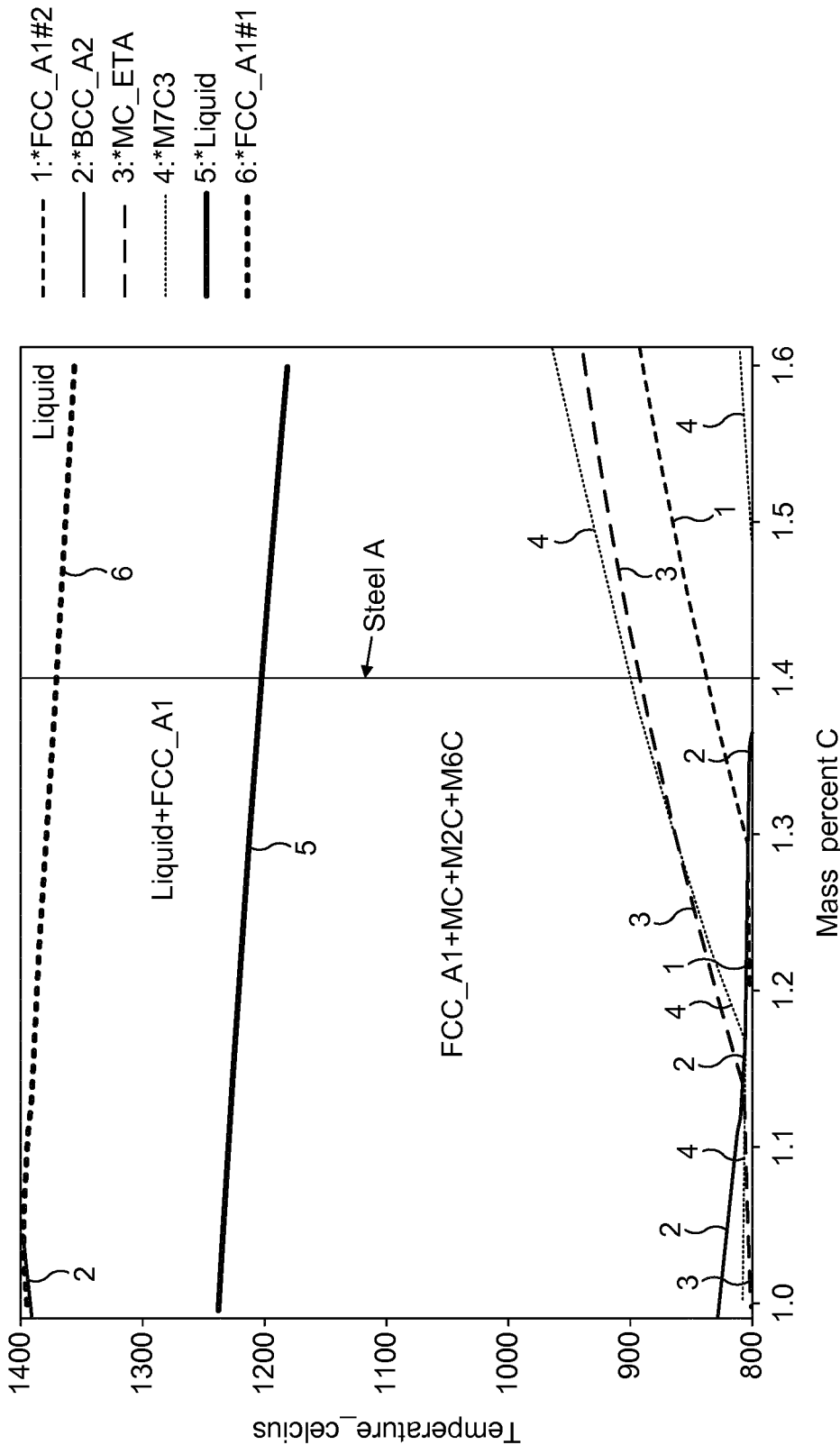


FIG. 1

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/050815

A. CLASSIFICATION OF SUBJECT MATTER		
INV.	C22C38/02 C22C38/22	C21D6/00 C22C38/24
	C21D6/02	C21D1/613
		C22C38/04
ADD.		
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 C21D		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	----- EP 1 024 208 A1 (HITACHI METALS LTD [JP]) 2 August 2000 (2000-08-02) claims 1-10 tables 1-2 paragraph [0016] - paragraph [0049]	1-15
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 18 June 2015		Date of mailing of the international search report 30/06/2015
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Vlassi, Eleni

INTERNATIONAL SEARCH REPORT

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Information on patent family members

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