



(11) **EP 4 151 766 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
22.03.2023 Bulletin 2023/12

(51) International Patent Classification (IPC):
C22C 38/42 ^(2006.01) **C22C 38/58** ^(2006.01)
C22C 1/02 ^(2006.01)

(21) Application number: **20934927.3**

(52) Cooperative Patent Classification (CPC):
C22C 1/02; C22C 38/42; C22C 38/58

(22) Date of filing: **12.05.2020**

(86) International application number:
PCT/KR2020/006209

(87) International publication number:
WO 2021/230392 (18.11.2021 Gazette 2021/46)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(72) Inventors:
• **SHIN, Hyunkwon**
Seoul 06772 (KR)
• **OH, Jinmok**
Seoul 06772 (KR)
• **KANG, Namseok**
Seoul 06772 (KR)

(71) Applicant: **LG Electronics, Inc.**
Yeongdeungpo-gu
Seoul 07336 (KR)

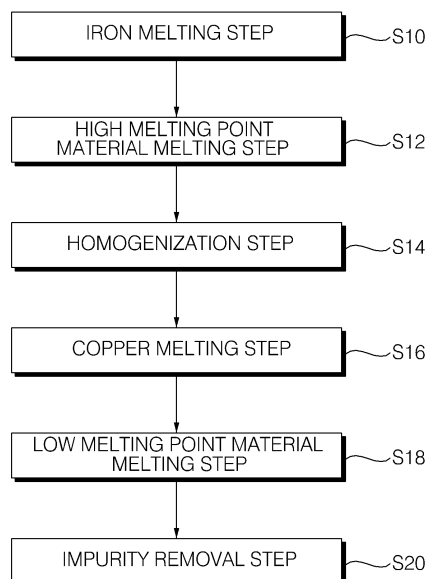
(74) Representative: **Ter Meer Steinmeister & Partner**
Patentanwälte mbB
Nymphenburger Straße 4
80335 München (DE)

(54) **HIGH-ENTROPY ALLOY AND METHOD FOR MANUFACTURING SAME**

(57) A high-entropy alloy according to the present embodiment is a high-entropy alloy having an iron-rich phase and a copper-rich phase, and comprises a common complete solid solution metal that is completely sol-

id-solved in iron and copper respectively. For example, the common complete solid solution metal may comprise nickel.

FIG. 1



EP 4 151 766 A1

Description**BACKGROUND**5 Field of the invention

[0001] The present disclosure relates to a high-entropy alloy and a method for manufacturing the same and, more particularly, to a high-entropy alloy and a method for manufacturing the same, which are improved in composition and process.

10 Related Art

[0002] With the development of various industries, the development of materials that may simultaneously exhibit opposite properties beyond the properties of a single material is required. In addition, due to regulations for protecting environment, it is required to reduce the weight of materials so as to improve the fuel efficiency of automobiles, the efficiency of electronic equipment, etc.

[0003] For example, in order to manufacture micro-parts with high strength and wear resistance, a high-entropy alloy with high fluidity and wettability, while simultaneously realizing opposite characteristics, i.e., excellent processability and strength, has been developed. In general, the high-entropy alloy is an alloy having a single-phase structure of a face-centered cubic structure (FCC) or a body-centered cubic structure (BCC) having a high mixed entropy by containing a plurality of elements in a predetermined amount or more.

[0004] However, the conventional high-entropy alloy is vulnerable to galvanic corrosion due to a difference in potential and a difference in melting point when different double phases are located in the same ratio, generates segregation during a casting process, or causes extraction or cracking of a low-temperature phase during a hot rolling process, so that it is difficult to manufacture the alloy as a sheet material. As such, corrosion resistance is not excellent, and castability and processability are not excellent, so that it is difficult to manufacture micro-parts.

SUMMARY

[0005] According to the present embodiment, there are provided a high-entropy alloy and a method for manufacturing the same, which have excellent corrosion resistance, castability, and processability while having excellent strength and wear resistance.

[0006] In particular, there are provided a high-entropy alloy and a method for manufacturing the same, which can have various properties according to a change in composition, have excellent productivity, or be manufactured by a simple manufacturing process.

[0007] A high-entropy alloy according to the present embodiment is an alloy having an iron-rich phase and a copper-rich phase, and includes a common complete solid solution metal that is completely solid-solved in iron and copper respectively. For instance, the common complete solid solution metal may include nickel (Ni).

[0008] The high-entropy alloy may further include a melting point lowering element for lowering a melting point of the high-entropy alloy. The melting point lowering element may include at least one of carbon (C), silicon (Si), phosphorus (P), and manganese (Mn). In addition, the high-entropy alloy may further include at least one of aluminum (Al), manganese (Mn), and chromium (Cr).

[0009] For example, the high-entropy alloy may include 15 to 80 at% iron, 1 to 30 at% copper, 1 to 20 at% nickel, 5 to 20 at% aluminum, 0 to 20 at% manganese, 0 to 15 at% chromium, 0 to 5 at% carbon, 0 to 2 at% silicon, 0 to 2 at% phosphorus, and other unavoidable impurities.

[0010] The content of the copper in the iron-rich phase may range from 1 to 30 at%.

[0011] The iron-rich phase may be contained in a larger volume ratio than the copper-rich phase to be present as a main phase, and the copper-rich phase may be partially present.

[0012] A method for manufacturing a high-entropy alloy according to an embodiment includes an iron melting step of melting an iron-containing material including a melting point lowering element and iron to form a molten metal; a high melting point material melting step of putting a high melting point element that has a melting point higher than that of the iron-containing material into the molten metal, and melting the high melting point element; a copper melting step of putting copper into the molten metal, and then melting the copper; and a low melting point material melting step of putting a low melting point material that has a melting point lower than that of the copper, and then melting the low melting point material.

[0013] The iron-containing material may include pig iron.

[0014] The melting point lowering element may include at least one of carbon, silicon, phosphorus, and manganese.

[0015] At least two of a first melting temperature of the iron melting step, a second melting temperature of the high

melting point material melting step, a third melting temperature of the copper melting step, and a fourth melting temperature of the low melting point material melting step may have different temperatures. The second melting temperature may be higher than the first melting temperature, the third melting temperature may be lower than the second melting temperature, and the fourth melting temperature may be lower than the third melting temperature.

[0016] The high-entropy alloy may include a common complete solid solution metal that is completely solid-solved in iron and copper respectively. Alternatively, the high melting point material may include at least one of nickel and chromium.

[0017] The low melting point material may include aluminum. In the low melting point material melting step, aluminum ingot may be pushed into a bottom portion of the molten metal to be melted.

[0018] A method for manufacturing a high-entropy alloy according to another embodiment a basic step of putting a plurality of materials including iron, copper, and a common complete solid solution metal that is completely solid-solved in iron and copper respectively; a step of forming inert gas atmosphere after vacuum; and a melting step of melting the plurality of materials.

[0019] The plurality of materials may further include at least one of carbon, silicon, phosphorus, aluminum, manganese, and chromium, and the common complete solid solution metal may include nickel.

[0020] The iron may include pig iron or pure iron.

[0021] According to the present embodiment, a high-entropy alloy having a double phase structure, i.e., an iron-rich phase and a copper-rich phase may include a common complete solid solution metal, thus reducing a difference in potential and a difference in melting point between the iron-rich phase and the copper-rich phase. This can prevent or minimize galvanic corrosion, effectively prevent segregation from being formed during casting, and prevent extraction or cracking of a low-temperature phase from occurring during hot rolling. Thus, it is possible to improve all of strength, fluidity, wettability, corrosion resistance, processability, and castability. Further, a material cost can be reduced by reducing a relatively expensive copper content and increasing a relatively inexpensive iron content. In this case, it is possible to manufacture a high-entropy alloy having various desired properties only by changing a composition, thereby improving productivity and quality.

[0022] In particular, because the high-entropy alloy according to the present embodiment has excellent castability, a 2mm mesh channel may be filled, so that it can be applied to a casting part that requires miniaturization and weight reduction, and the degree of freedom in design can be increased, thus improving a variety of performance. Such a high-entropy alloy can be melted and manufactured under atmospheric conditions by controlling an input sequence and a melting temperature, thus improving productivity, and can be melted and manufactured in a process using vacuum, thus simplifying a manufacturing process.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023]

FIG. 1 is a flowchart illustrating a method of manufacturing a high-entropy alloy of an embodiment of the disclosure. FIG. 2 is a flowchart illustrating a method of manufacturing a high-entropy alloy of another embodiment of the disclosure.

FIG. 3 is a field emission scanning electron microscope (FE-SEM) photograph of a high-entropy alloy of example 1.

FIG. 4 is a photograph in which a salt spray test is performed on the high-entropy alloy of the example 1.

FIG. 5 is a photograph in which a salt spray test is performed on a high-entropy alloy of a comparative example 1.

FIG. 6 is a photograph in which a salt spray test is performed on a high-entropy alloy of an example 2.

FIG. 7 is a photograph in which a salt spray test is performed on a high-entropy alloy of an example 3.

FIG. 8 is a photograph of a sheet material that is formed by processing the high-entropy alloy of the example 1.

FIG. 9 is a photograph of an Oldham ring having the thickness of 1.7mm manufactured using the high-entropy alloy of the example 1.

FIGS. 10(a) and (b) are photographs of the results of performing 2mm mesh channel evaluation on high-entropy alloys of examples 5 and 6, respectively.

FIG. 11 is a photograph of the result of performing 2mm mesh channel evaluation on cast iron of a comparative example 4.

FIGS. 12(a) and (b) are photographs of the results of performing wear-resistance evaluation on the high-entropy alloys of the examples 5 and 6, respectively.

FIGS. 13(a), (b) and (c) are photographs of the results of performing wear-resistance evaluation on cast iron or high-entropy alloy of comparative examples 4, 5, and 6, respectively.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0024] Hereinafter, a high-entropy alloy and a method for manufacturing the same according to an embodiment of the

present disclosure will be described in detail.

[0025] Herein, the high-entropy alloy is a term that is used to distinguish it from a low-entropy alloy, and may collectively refer to an alloy having the entropy of a certain level or higher. For example, herein, the high-entropy alloy may include an alloy that has the entropy of 1.5R or more and is generally referred to as a high-entropy alloy, as well as an alloy that has the entropy of 1.0R or more and is generally referred to as a medium-entropy alloy. That is, the high-entropy alloy according to the present embodiment may have the entropy of 1.0R or more.

[0026] The high-entropy alloy according to the present embodiment is a high-entropy alloy having an iron-rich phase and a copper-rich phase, and may include a common complete solid solution metal that is completely solid-solved in iron and copper, respectively, or forms a complete solid solution with each of iron and copper. For example, the common complete solid solution metal may include nickel (Ni). Herein, the iron-rich phase may mean a phase having the highest iron content (e.g., at%) among a plurality of materials (e.g., elements) constituting the phase, and the copper-rich phase may mean a phase having the highest copper content (e.g., at%) among a plurality of materials (e.g., elements) constituting the phase.

[0027] In order to improve various properties of the high-entropy alloy, the high-entropy alloy may further include at least one of aluminum, manganese, and chromium. In addition, the high-entropy alloy may further include a melting point lowering element (melting point lowering material) for lowering the melting point of the high-entropy alloy, and the melting point lowering element may include carbon, silicon, phosphorus, manganese, etc.

[0028] Since iron is inexpensive, has excellent strength and ductility, and is greatly changed in strength and hardness depending on a phase structure, it may be easily adjusted so that the high-entropy alloy has desired properties. The copper is low in melting point, and is excellent in electric conductivity and thermal conductivity. Further, the copper is not mixed with iron and forms a double phase structure having the iron-rich phase and the copper-rich phase, so that it is suitable for forming the high-entropy alloy capable of improving both iron properties and copper properties.

[0029] Since the high-entropy alloy according to the present embodiment contains iron and copper that are not mixed well with each other, they are not mixed with each other unless other metals are contained, thus making it difficult to form the alloy. Thus, in order to prevent phase separation between iron and copper, the alloy may be formed to contain aluminum, manganese, etc. having a predetermined solid solubility in each of iron and copper. Accordingly, the high-entropy alloy has the iron-rich phase and the copper-rich phase, but may be changed in the ratio of the iron-rich phase and the copper-rich phase depending on the contents of iron and copper.

[0030] In the present embodiment, it may form a complete solid solution with iron, form a complete solid solution with copper having a high solid solubility in iron, or include a common completely solid-solved metal having a high solid solubility in copper. For example, nickel that is completely solid-solved with copper, is completely solid-solved with iron with a high solid solubility, or has a high solid solubility may be used as a common complete solid solution metal. As such, if the common completely solid-solved metal (e.g. nickel) is contained, this may increase the solid solubility of copper in the iron-rich phase in the high-entropy alloy having the double phase structure of the iron-rich phase and the copper-rich phase, and increase the solid solubility of iron in the copper-rich phase, thus reducing a difference in potential and a difference in melting point between the iron-rich phase and the copper-rich phase. Thereby, it is possible to prevent or minimize galvanic corrosion that may be caused by the difference in potential between the iron-rich phase and the copper-rich phase. Further, it is possible to effectively prevent the formation of segregation that may occur during casting by a difference in melting point between the iron-rich phase and the copper-rich phase, and effectively prevent the extraction or cracking of the low-temperature phase during hot rolling. Thus, it is easy to perform casting or hot rolling. Moreover, nickel has excellent corrosion resistance, so that it is possible to improve the corrosion resistance of the high-entropy alloy.

[0031] The inclusion of nickel may increase the solid solubility of copper in the iron-rich phase, thus reducing a copper content throughout the high-entropy alloy. Thus, a material cost can be reduced by reducing the content of copper that is relatively expensive and increasing the content of iron that is relatively inexpensive. Further, it is possible to lower a melting temperature and improve corrosion resistance in the process of manufacturing the high-entropy alloy.

[0032] In the present embodiment, the double phase structure including the iron-rich phase and the copper-rich phase may be obtained, and their ratios may not be equal. For example, the iron-rich phase is contained in a larger volume ratio than the copper-rich phase to be present as a main phase, and the copper-rich phase is partially present to prevent the formation of segregation, thus resulting in high strength, processability, castability, and wettability, and thereby causing the high-entropy alloy to have a uniform composition.

[0033] For example, the content of copper in the iron-rich phase may range from 5 to 30 at% (e.g., 10 to 25 at%). This is set in consideration of the content of nickel contained in the high-entropy alloy, but the present disclosure may have various values without being limited thereto. For reference, the content of copper in the iron-rich phase that does not include nickel may be less than 5 at% (e.g., 3 at% or less).

[0034] Further, aluminum is a lightweight element (lightweight material), and is mixed with iron as the low melting point element (low melting point material) to form a body-centered cubic structure. Aluminum may improve hardness, wear resistance, strength, etc. but may reduce ductility. If manganese is contained in iron, this may improve both strength

and ductility. Further, manganese is lower in melting point than iron, and may act as a type of melting point lowering element for lowering the melting point of the high-entropy alloy. Thus, the fluidity and castability of the high-entropy alloy can be improved. When chromium is included in iron, a chromium oxide film may be formed on iron or the iron-rich phase to further improve corrosion resistance. Chromium may or may not be included in the high-entropy alloy.

[0035] If the melting point is lowered by the melting point lowering element such as carbon, silicon, phosphorus, or manganese, this has excellent fluidity and wettability and low high-temperature viscosity during the manufacturing process of the high-entropy alloy, thus improving castability. The melting temperature is low when a molten metal is made, so that it is possible to perform casting under atmospheric conditions even if the low melting point material such as copper or aluminum is contained. Thus, the quality of the high-entropy alloy can be improved. Here, when silicon is included as the low melting point element, castability can be improved and corrosion resistance can be improved by forming an oxide. When carbon is included as the low melting point element, the melting point can be effectively lowered. When phosphorus is included as the low melting point element, the melting point can be effectively lowered even with a small amount of phosphorus.

[0036] For example, the high-entropy alloy may include 15 to 80 at% iron, 1 to 30 at% copper, 1 to 20 at% nickel, 5 to 20 at% aluminum, 0 to 20 at% (e.g. 0.1 to 20 at%, e.g. 5 to 20 at%) manganese, 0 to 15 at% (e.g. 2 to 15 at%) chromium, 0 to 5 at% (e.g., 3 to 5 at%) carbon, 0 to 2 at% silicon (e.g. 1 to 2 at%), 0 to 2 at% (e.g., 0 to 1 at%) phosphorus, other elements or unavoidable impurities.

[0037] To be more specific, if the content of iron is less than 15 at%, strength and ductility may be reduced. If the content of iron is more than 80 at%, the contents of other metals may be reduced and thereby it may be difficult to improve various properties in the high-entropy alloy. If the content of copper is less than 1 at%, the effects of lowering the melting point and improving the electric conductivity or the thermal conductivity using copper may not be sufficient. If the content of copper is more than 30 at%, the contents of other metals may be reduced and thereby it may be difficult to improve various properties in the high-entropy alloy.

[0038] If the content of nickel is less than 1 at%, the above-described effect may not be sufficient by nickel. If the content of nickel is more than 20 at%, the contents of iron and copper are not sufficient, so that it may be difficult to improve various properties in the high-entropy alloy.

[0039] If the content of aluminum is less than 5 at%, the effect of aluminum may not be sufficient. If the content of aluminum is more than 20 at%, the contents of iron and copper are not sufficient, so that it may be difficult to improve various properties in the high-entropy alloy and the ductility of the high-entropy alloy may be reduced. Manganese may or may not be included in the high-entropy alloy. When manganese is included in the high-entropy alloy, for instance, manganese may be included in the amount of 0.1 to 20 at% (e.g., 5 to 20 at%). This is to improve the effect of manganese while sufficiently maintaining the contents of iron, copper, etc. Chromium may or may not be included in the high-entropy alloy. When chromium is contained in the high-entropy alloy, for instance, chromium may be included in the amount of 2 at% to 15 at%. This is to improve the effect of chromium while sufficiently maintaining the contents of iron, copper, etc.

[0040] Further, if the content of silicon is more than 2 at%, a precipitated phase may be formed in the high-entropy alloy, thus causing cracks in a cast product. If silicon is included in the amount of 1 at% or more, the effect of silicon may be sufficiently realized. If the content of carbon is more than 5 at%, it may be difficult to sufficiently maintain the contents of iron, copper, etc. and the melting point of the high-entropy alloy may be increased. When the high-entropy alloy contains carbon and the content of carbon ranges from 3 to 5 at%, the melting point may be effectively lowered. Further, phosphorus may be included in the amount of 2 at% or less so as not to significantly affect other properties while effectively lowering the melting point.

[0041] However, the present disclosure is not limited to the above-described elements and contents. Therefore, the present disclosure may further include elements or materials as well as the above-described elements or contents, and the content of each element or material may be variously changed in consideration of the desired properties of the high-entropy alloy.

[0042] The high-entropy alloy according to the present embodiment may be used to manufacture various products. That is, the high-entropy alloy according to the present embodiment has both excellent fluidity and wettability due to copper, so that it is more excellent in castability than cast iron, and thereby it may fill a 2mm mesh channel. This may be applied to a cast part requiring miniaturization. Further, a reduction in weight may be realized by thinly forming a part that requires a reduction in weight. Furthermore, a variety of performance can be improved by increasing the degree of freedom in design of a cast product due to the casting possibility of a precise design. At this time, a high-entropy alloy having various desired properties can be manufactured merely by changing a composition.

[0043] For example, it is possible to manufacture an Oldham ring that prevents the rotation of a scroll in a scroll compressor and enables only the leftward or rightward revolution of the scroll, using the high-entropy alloy according to the present embodiment. The weight reduction of the Oldham ring is required to reduce noise and improve efficiency during an operation. For example, the Oldham ring should be manufactured to have the overall weight of 100g or less, and a key part holding the scroll so as to be coupled with the scroll in the Oldham ring should be precisely machined to have only the error of $\pm 5\text{mm}$. As described above, the high-entropy alloy according to the present embodiment has

castability that may fill the 2mm mesh channel, so that the Oldham ring having the thickness of 2mm or less may be manufactured and a specific gravity may also be adjusted to 7.2 or less, thus providing a lighter weight compared to the Oldham ring made of general iron alloy.

[0044] An example of a method for manufacturing the above-described high-entropy alloy will be described in detail with reference to FIG. 1. A detailed description of the same or similar parts to those of the above description will be omitted and only different parts will be described in detail. The above-described contents will be applied to the contents of materials contained in the high-entropy alloy.

[0045] FIG. 1 is a flowchart illustrating a method of manufacturing a high-entropy alloy according to an embodiment of the present disclosure.

[0046] Referring to FIG. 1, the manufacturing method of the high-entropy alloy according to the present embodiment may include an iron melting step S10, a high melting point material melting step S12, a homogenization step S14, a copper melting step S16, a low melting point material melting step S18, and an impurity removal step S20. In the manufacturing method of the high-entropy alloy, it is possible to cast the high-entropy alloy under atmospheric pressure conditions (i.e. general atmospheric pressure conditions, i.e. atmospheric conditions) other than a vacuum condition. This will be described in more detail.

[0047] First, in the iron melting step S10, a molten metal may be formed by introducing an iron-containing material into molten metal manufacturing equipment and then melting the material. Various types of known equipment may be used as the molten metal manufacturing equipment.

[0048] In the present embodiment, the iron-containing material may include iron and a melting point lowering element. For example, pig iron or pig iron and manganese may be used as the iron-containing material. Since the pig iron contains the melting point lowering element such as carbon, silicon, manganese, or phosphorus together with iron, the pig iron may be used as it is and the melting point lowering element may be introduced together. Here, the pig iron may include 5 at% (e.g. 3 to 5 at%) carbon, and 1 to 2 at% silicon, manganese, phosphorus, or the like.

[0049] In the iron melting step S10, the melting point lowering element may be melted together with iron to lower the melting point of iron and thereby effectively lower a first melting temperature. In particular, by basically reducing the melting point of iron, it is possible to lower the fourth melting temperature in the low melting point material melting step S18 performed after adding the low melting point element, such as aluminum or copper, having a low melting point. Thus, in the low melting point material melting step S18, it is possible to prevent aluminum or copper from being oxidized at high temperature (e.g. 1600°C or higher, i.e., more than 1520°C). This will be described in more detail later in the low melting point material melting step S18.

[0050] For example, the first melting temperature of the iron melting step S10 may range from 1450 to 1520°C. In this temperature range, the iron-containing material can be stably melted and a burden in the high-temperature process can be reduced. However, the present disclosure is not limited thereto, and the melting temperature of the iron melting step S10 may be variously changed.

[0051] Subsequently, in the high melting point material melting step S12, the high melting point material having a melting point higher than that of the iron-containing material may be put into the molten metal to be melted. The high melting point material may include a common complete solid solution metal that is completely solid-solved in iron and copper respectively. For example, the common complete solid solution metal may include nickel. Alternatively, the high melting point material may further include chromium.

[0052] At this time, the second melting temperature of the high melting point material melting step S12 may be higher than the first melting temperature of the iron melting step S10. For example, the second melting temperature of the high melting point material melting step S12 may range from 1650 to 1750°C. In this temperature range, a material including chromium, nickel, etc. can be stably melted and a burden caused by the high-temperature process can be reduced. However, the present disclosure is not limited thereto, and the second melting temperature of the high melting point material melting step S12 may be variously changed.

[0053] Subsequently, the homogenization step S14 may be performed at a homogenization temperature lower than the second melting temperature. At this time, in order to remove impurities, homogenization may be performed by including flux. For example, the flux used to remove the impurities may include Al_2O_3 , CaO , SiO_2 , etc. However, the present disclosure is not limited thereto, and the introduction of the flux, the material of the flux, etc. may be variously changed.

[0054] For example, the homogenization temperature of the homogenization step S14 may range from 1450 to 1520°C. In this temperature range, homogenization and stabilization may be stably performed, and impurities may be removed. The homogenization step S14 or the impurity removal process included therein may be performed for 1 minute to 10 minutes (e.g., 2 to 3 minutes). The impurities may be stably removed in this time range, and it is possible to prevent productivity from being deteriorated due to excessively long process time. However, the present disclosure is not limited thereto, and the homogenization temperature and/or the process time of the homogenization step S14 may be variously changed.

[0055] Subsequently, in the copper melting step S16, copper may be put into the molten metal to be melted.

[0056] The third melting temperature of the copper melting step S16 may be equal to or higher than the first melting temperature of the iron melting step S10 and the uniformization temperature of the homogenization step S14, and may be equal to or lower than the second melting temperature of the high melting point material melting step S12. For instance, the third melting temperature may be higher than the first melting temperature of the iron melting step S10 and the uniformization temperature of the homogenization step S14, and may be lower than the second melting temperature of the high melting point material melting step S12.

[0057] For example, the third melting temperature of the copper melting step S16 may range from 1520 to 1650°C. The molten metal in the copper melting step S16 contains a large amount of elements or materials having a low melting point, including copper of a low melting point, to have a relatively melting point (i.e. melting point of 1150°C or less, such as 900°C to 1100°C). If the third melting temperature is defined as described above in consideration of the melting efficiency along with the melting point, copper may be stably melted after the copper is added, and a burden in the high-temperature process may be reduced. However, the present disclosure is not limited thereto and the melting temperature of the copper melting step S16 may be variously changed.

[0058] Subsequently, in the low melting point material melting step S18, the low melting point material having the melting point lower than that of iron or the iron-containing material may be put into the molten metal to be melted. The low melting point material may include aluminum or the like. Here, aluminum may be pushed in the form of an ingot into a bottom portion of the molten metal, and then be melted or dissolved. Thereby, it is possible to minimize or prevent aluminum oxide formed by oxidizing aluminum from floating on a surface of the molten metal.

[0059] At this time, the fourth melting temperature of the low melting point material melting step S18 may be equal to or higher than the temperature of the copper melting step S16. For example, the fourth melting temperature of the low melting point material melting step S18 may be lower than the temperature of the copper melting step S16. This is to minimize a problem such as the oxidization of the low melting point material. For instance, the fourth melting temperature of the low melting point material melting step S18 may be 1500°C or less (e.g., 1200 to 1400°C). If the fourth melting temperature is more than 1500°C (e.g., 1400 °C), aluminum is melted and simultaneously oxidized to form slag composed of aluminum oxide over the molten metal. Thus, a process of removing the slag should be added. If the fourth melting temperature is 1200°C or less, a homogeneous molten metal may not be formed. However, the present disclosure is not limited thereto and the melting temperature of the low melting point material melting step S18 may be variously changed.

[0060] Subsequently, in the impurity removal step S20, impurities (e.g. oxide, slag or the like present on the surface of the molten metal) may be removed using the flux. The flux used for removing the impurities may include Al_2O_3 , CaO , SiO_2 , etc. However, the present disclosure is not limited thereto. Therefore, the impurity removal step S20 may not be performed, and the introduction of the flux, the material of the flux, etc. may be variously changed in the impurity removal step S20.

[0061] A final molten metal from which impurities are removed may be tapped at a predetermined tapping temperature (e.g., 1400 to 1600°C, such as 1500°C), and be processed to have a desired shape (e.g., casting using a mold having a desired shape). However, the present disclosure is not limited thereto, and the tapping temperature or the like may be variously changed.

[0062] In the manufacturing method of the high-entropy alloy according to the present embodiment, it is possible to perform processing or casting under atmospheric pressure conditions (i.e. general atmospheric pressure conditions) other than the vacuum condition, thereby reducing manufacturing costs, and allowing various parts of a desired shape to be manufactured. In particular, pig iron with low purity may be used and impurities may be easily removed, so that the quality of the manufactured high-entropy alloy may be excellent. Further, since there is no limitation on the number of molds, the final molten metal may be sequentially poured into the prepared molds to manufacture a large number of cast products together, thereby reducing costs.

[0063] In contrast, in casting using a vacuum process, it may be difficult to pour the molten metal into the mold after manufacturing the final molten metal, and it may be difficult to reduce the manufacturing cost. Further, it may be relatively disadvantageous in terms of process time and cost, and if a high-purity material is not used, it may be difficult to remove impurities in the final molten metal, so the quality of the finished high-entropy alloy may be low. Further, since the number of molds that may be put into the vacuum chamber is limited, it is difficult to manufacture a cast product, and a device capable of picking the molten metal out of the vacuum chamber should be prepared in order to inject the final molten metal into the external mold. Accordingly, there may be difficulties in the process and an increase in cost.

[0064] Further, in the manufacturing method of the high-entropy alloy according to the present embodiment, at least two of the first to fourth melting temperature are different from each other. That is, in the present embodiment, the molten metal may be manufactured by adjusting the input sequence and the melting temperature in consideration of different melting points of a plurality of materials or elements contained in the high-entropy alloy, thus allowing the high-entropy alloy to have a uniform composition, preventing cracks from occurring, and thereby improving a quality. In contrast, in conventional atmospheric casting without controlling the pouring sequence and melting temperature, oxidation of a low melting point element (e.g. aluminum) occurs during molten metal production, resulting in non-uniform composition, or

cracking due to ingress of oxide when pouring molten metal into the mold.

[0065] Since the high-entropy alloy according to the present embodiment has excellent fluidity and wettability by including the melting point lowering element, it may be stably injected into the mold merely by maintaining a temperature level of about 1400°C.

[0066] Another example of a method for manufacturing the above-described high-entropy alloy will be described in detail with reference to FIG. 2. A detailed description of the same or similar parts to those of the above description will be omitted and only different parts will be described in detail.

[0067] FIG. 2 is a flowchart illustrating a method of manufacturing a high-entropy alloy according to another embodiment of the present disclosure.

[0068] Referring to FIG. 2, the present embodiment may include a preparation step S30, a step S32 of forming an inert gas atmosphere after vacuum, and a melting step S34.

[0069] First, in the preparation step S30, all materials for manufacturing the high-entropy alloy may be put into the molten metal manufacturing equipment. Here, iron may be pure iron or pig iron.

[0070] Subsequently, in the step S32 of forming the inert gas atmosphere after vacuum, the inert gas atmosphere may be formed while performing a washing operation in a chamber by repeatedly injecting inert gas after creating the vacuum atmosphere. Examples of the inert gas atmosphere may include an argon (Ar) gas atmosphere.

[0071] Subsequently, in the melting step S34, the molten metal may be manufactured by performing a melting operation at a predetermined melting temperature. For example, the melting temperature of the melting step S34 may be 1750°C or less (e.g. 1650°C or less), in detail, 1200°C to 1750°C (e.g. 1400°C to 1650°C, such as 1450°C to 1520°C). However, the melting temperature of the melting step S34 may be variously changed by the material forming the high-entropy alloy.

[0072] When the melting step S34 is completed, a tapping operation may be performed at a predetermined tapping temperature (e.g., 1400 to 1600°C, such as 1500°C), and then a process may be performed to have a desired shape (e.g., casting using a mold having a desired shape). However, the present disclosure is not limited thereto, and the tapping temperature or the like may be variously changed.

[0073] According to the present embodiment, the melting step S34 is performed under the inert gas atmosphere after vacuum, thus effectively preventing the low melting point material from being lost by oxidation (e.g. the loss of aluminum). In particular, when the high-entropy alloy contains a large amount of low melting point element (e.g. aluminum), the manufacturing method according to the present embodiment can more effectively prevent the loss of the low melting point material. Since it is unnecessary to consider the melting points of various materials included in the high-entropy alloy, the manufacturing process can be simplified by a single melting step (S34). Thus, the high-entropy alloy having the desired composition can be easily manufactured through a simple process.

[0074] On the other hand, in conventional atmospheric casting having the single melting step in which the input sequence and the melting temperature are not controlled, oxidation of the low melting point element (e.g., aluminum) occurs during molten metal production, thereby causing the large loss of the low melting point element and deteriorating fluidity. In addition, when the molten metal is poured into the mold, oxide is introduced, which may cause problems such as cracks in the cast product.

[0075] Hereinafter, the present disclosure will be described in more detail through experimental examples of the present disclosure. However, the experimental examples of the present disclosure are merely illustrative of the present disclosure, and the present disclosure is not limited thereto.

Example 1

[0076] A high entropy alloy having a composition according to Table 1 and a chemical formula of $\text{Al}_{15}\text{Ni}_{15}\text{Cr}_{10}(\text{CuFe})_{50}\text{Mn}_{10}$ was manufactured using the manufacturing method shown in FIG. 1. In this case, the iron-containing material used 4.67 at% carbon, 1.35 at% silicon, 0.27 at% manganese, 0.11 at% phosphorus, 0.02 at% sulfur, 0.08 at% titanium, 0.01 at% vanadium, pig iron containing the remainder of iron, and additional manganese.

Example 2

[0077] A high-entropy alloy was manufactured in the same manner as in Example 1, except that it has the chemical formula of $\text{Al}_{15}\text{Ni}_5\text{Cr}_{10}\text{Cu}_{10}\text{Fe}_{43}\text{Mn}_{15}\text{Si}_2$.

Example 3

[0078] A high-entropy alloy was manufactured in the same manner as in Example 1, except that it has the chemical formula of $\text{Al}_{15}\text{Ni}_5\text{Cr}_{10}\text{Cu}_{10}\text{Fe}_{40}\text{Mn}_{13}\text{Si}_2$.

Example 4

[0079] A high-entropy alloy was manufactured in the same manner as in Example 1, except that it has the chemical formula of $\text{Al}_{15}\text{Ni}_5\text{Cr}_{10}\text{Cu}_{10}\text{Fe}_{40}\text{Mn}_{20}$.

Example 5

[0080] A high-entropy alloy was manufactured in the same manner as in Example 1, except that it has the chemical formula of $\text{Al}_{17}\text{Ni}_3\text{Cr}_5\text{Cu}_{15}\text{Fe}_{45}\text{Mn}_{15}$.

Example 6

[0081] A high-entropy alloy was manufactured in the same manner as in Example 1, except that it has the chemical formula of $\text{Al}_{13}\text{Ni}_3\text{Cr}_6\text{Cu}_8\text{Fe}_{55}\text{Mn}_{15}$.

Comparative Example 1

[0082] A high entropy alloy having a composition according to Table 2 and a chemical formula of $\text{Al}_{10}\text{Cr}_{20}(\text{CuFe})_{60}\text{Mn}_{10}$ was manufactured by performing a single melting process in a vacuum.

Comparative Example 2

[0083] A stainless steel (SUS316) was prepared.

Comparative Example 3

[0084] A stainless steel (SUS304) was prepared.

Comparative Example 4

[0085] Cast iron (GC250) was prepared.

Comparative Example 5

[0086] A high-entropy alloy was manufactured in the same manner as in Comparative Example 1, except that it was manufactured using pure iron and had the chemical formula of $\text{Al}_{15}\text{Cr}_5(\text{FeCuMn})_{80}$.

Comparative Example 6

[0087] A high-entropy alloy was manufactured in the same manner as in Comparative Example 1, except that it was manufactured using pig iron and had the chemical formula of $\text{Al}_{15}\text{Cr}_5(\text{FeCuMn})_{80}$.

Composition Analysis

[0088] A field emission scanning electron microscope (FE-SEM) photograph of the high-entropy alloy according to Example 1 is shown in FIG. 3. For reference, the compositions of Tables 1 and 2 were measured by an energy dispersive spectrometry (EDS), and the content of each element was expressed in at%.

Table 1

	Fe	Cu	Al	Mn	Cr	Ni
Iron-rich	25.51	16.01	17.69	6.65	10.12	24.02
phase						
Copper-rich phase	6.04	64.31	10.75	6.37	0.88	11.65

Table 2

	Fe	Cu	Al	Mn	Cr
Iron-rich phase	47.07	2.44	7.37	10.87	32.26
Copper-rich phase	3.56	73.48	11.30	9.88	1.77

[0089] Referring to Tables 1 and 2, it can be seen that the content of copper in the iron-rich phase in the high-entropy alloy according to Example 1 containing nickel was 16.01 at%, which was significantly higher compared to Comparative Example 1 in which there was no nickel and the content of copper in the iron-rich phase in the high-entropy alloy was 2.44 at%. Further, it can be seen that the content of iron in the copper-rich phase in the high-entropy alloy according to Example 1 containing nickel was 6.04 at%, which was higher compared to Comparative Example 1 in which there was no nickel and the content of iron in the copper-rich phase in the high-entropy alloy was 3.56 at%. That is, it can be seen that the copper content in the iron-rich phase and the iron content in the copper-rich phase in the high-entropy alloy according to Example 1 containing nickel are increased. Thereby, it can be seen that copper or iron is dissolved at a certain level or more in the iron-rich phase and the copper-rich phase in the high-entropy alloy according to Example 1, so that a corrosion potential difference between the iron-rich phase and the copper-rich phase may be reduced.

[0090] Further, referring to FIG. 3, it can be seen that the iron-rich phase and the copper-rich phase having different brightness are coexisted in the high-entropy alloy according to Example 1. At this time, it can be seen that the iron-rich phase is present as the main phase and the copper-rich phase is partially present.

Salt Spray Test - Corrosion Resistance

[0091] A salt spray test was performed on the high-entropy alloy according to Example 1 and Comparative Example 1. In the salt spray test, 5wt% of sodium chloride salt water was indirectly continuously sprayed with the nozzle pressure of 1.0 kg/cm², and the pH of 6.5 to 7.2 and the temperature of 35°C were maintained. FIG. 4(a) shows a photograph before the salt spray test of the high-entropy alloy according to Example 1, FIG. 4(b) shows a photograph when maintained for 24 hours while spraying salt water, FIG. 4(c) shows a photograph when maintained for 72 hours while spraying salt water. In addition, FIG. 5 shows a photograph when maintained for 24 hours while spraying salt water onto the high-entropy alloy according to Comparative Example 1.

[0092] Referring to FIG. 4, it can be seen that the high-entropy alloy according to Example 1 containing nickel was not significantly corroded even if salt spray was performed for a long time. On the other hand, referring to FIG. 5, it can be seen that the high-entropy alloy according to Comparative Example 1 containing no nickel was greatly corroded by salt spray and thus stained. Accordingly, it can be seen that the alloy according to Example 1 including nickel has excellent corrosion resistance.

Potentiodynamic Polarization Test - Corrosion Resistance

[0093] The high-entropy alloy according to Example 1 and the stainless steel according to Comparative Example 2 were subjected to a potentiodynamic polarization test, and the results are shown in Table 3. In the potentiodynamic polarization test, a 5 wt% sodium chloride aqueous solution was used, Ag/AgCl was used as a reference electrode, and a scan rate was 0.33 (dE/dt).

Table 3

	Example 1	Comparative Example 2
Corrosion Potential [V]	-0.37	-0.2
Dynamic Equilibrium Current Density [log (A/cm ²)]	-7.6	-7.6

[0094] Referring to Table 3, it can be seen that the high-entropy alloy according to Example 1 has high corrosion resistance similar to that of the stainless steel according to Comparative Example 2 having high corrosion resistance.

Salt Spray Test - Corrosion Resistance

[0095] A salt spray test was performed on the high-entropy alloy according to Examples 2 and 3. In the salt spray test, 5wt% of sodium chloride salt water was indirectly continuously sprayed with the nozzle pressure of 1.0 kg/cm², and the

pH of 6.5 to 7.2 and the temperature of 35°C were maintained. FIG. 6(a) shows a photograph before the salt spray test of the high-entropy alloy according to Example 2, and FIG. 6(b) shows a photograph when maintained for 24 hours while spraying salt water. In addition, FIG. 7(a) shows a photograph before the salt spray test of the high-entropy alloy according to Example 3, and FIG. 7(b) shows a photograph when maintained for 24 hours while spraying salt water.

[0096] Referring to FIGS. 6 and 7, it can be seen that corrosion rarely occurred even when salt spray was performed on the high-entropy alloys according to Examples 2 and 3 having the nickel content of 5 at%. For instance, it can be seen that even when the content of nickel is not as large as 5 at%, excellent corrosion resistance can be obtained if the composition also contains silicon. It is expected that the corrosion resistance is improved by the formation of the oxide including silicon together. When silicon is included and the content of nickel is reduced as described above, the material cost of a high-entropy alloy having excellent properties can be reduced by reducing the content of expensive nickel.

Grindability

[0097] The high entropy alloys according to Examples 1 and 4 and the stainless steel according to Comparative Example 3 were lathe-processed. Lathe processing was performed under the conditions of the rotation speed of 10000 rpm, the movement speed of 5000 feed, a tool of 6 pie, REM (0.5R), the depth of 0.7 mm (AP), and spacing (AE) of 70% of a tool diameter, and watersoluble cutting oil was used.

[0098] FIG. 8 shows a photograph of a sheet material that is formed by processing the high-entropy alloy according to Example 1. Referring to FIG. 8, it can be seen that a cleanly processed sheet material may be manufactured using the alloy according to Example 1. For example, processing is possible in this example without defects or damage even at a processing speed 4 times faster than that of stainless steel as in Comparative Example 3. Thus, a processing time can be shortened when applied to an actual processed product. Further, in Example 1, there was no breakage of the tool even at a high processing speed. Thereby, it can be seen that it is possible to provide the cleanly processed sheet material at a high processing speed.

[0099] Further, the processing speeds (grinding rates) and copper contents of the high-entropy alloys according to Examples 1 and 4, and the stainless steel according to Comparative Example 3 are shown in Table 4. At this time, the processing speed per unit area was measured at a speed of 300 rpm under a load of 800g.

Table 4

	Processing Speed [s/mm ²]	Copper Content [at%]
Example 1	1.37	25
Example 4	2.92	10
Comparative Example 3	3.33	-

[0100] Referring to Table 4, it can be seen that the processing speeds in the high-entropy alloys according to Examples 1 and 4 are significantly higher than the processing speed of the stainless steel according to Comparative Example 3. For example, if the copper content is 25 at% or more as in the high-entropy alloy according to Example 1, the processing speed may be twice or more than the processing speed of the stainless steel according to Comparative Example 3. This is because the copper-rich phase having excellent grindability or machinability was mixed or interspersed with the iron-rich phase having high strength, in the case of the high-entropy alloys according to Examples 1 and 4.

Castability

[0101] FIG. 9 shows the photograph of the Oldham ring having the thickness of 1.7 mm manufactured using the high-entropy alloy according to Example 1. Further, FIGS. 10(a) and 10(b) show photographs taken as the result of performing 2mm mesh channel evaluation on the high-entropy alloys according to Examples 5 and 6, and FIG. 11 shows a photograph taken as the result of performing 2mm mesh channel evaluation on the cast iron according to Comparative Example 4.

[0102] In addition, FIGS. 12(a) and 12(b) show photographs taken as the result of performing wear resistance evaluation on the high-entropy alloys according to Examples 5 and 6, and FIGS. 13(a), 13(b), and 13(c) show photographs taken as the result of performing wear resistance evaluation on the cast iron or high-entropy alloys according to Comparative Examples 4, 5, and 6. Further, the hardness, 2mm micro-channel fillability, wear-track width, and entropy of the high-entropy alloys or cast iron according to Examples 5 and 6 and Comparative Examples 4, 5 and 6 were measured, and then the results are shown in Table 5. The wear resistance evaluation was performed using a ball made of aluminum oxide (Al₂O₃) under the conditions of a normal drag of 10N, a rotational speed of 300rpm, a rotational radius of 11.5mm, and a time of 3000 seconds.

Table 5

	Strain	Hardness [Hv]	Fillability[%]	Wear-track width [um]	Entropy
Example 5	0.025	374	81	2313-2373	1.48R
Example 6	0.03	324	85	3059-3782	1.40R
Comparative Example 4	0.036	-	77	1792-2051	-
Comparative Example 5	0.015	391	68	1468-2409	1.49R
Comparative Example 6	0.039	238	79	1252-3007	1.49R

[0103] Referring to FIG. 9, it can be seen that, when using the high-entropy alloy according to Example 1, the Oldham ring having the thickness of 1.7 mm may be formed by precise processing.

[0104] Referring to FIGS. 10 and 11 and Table 5, it can be seen that the high entropy alloys according to Examples 5 and 6 have better castability than the cast iron according to Comparative Example 4 having excellent castability in the evaluation of the 2mm mesh channel. This is because the high entropy alloys according to Examples 5 and 6 have high fluidity and have large wettability due to low surface energy, so that a micro mesh channel mold may be stably filled. In particular, since copper components included in the high entropy alloys according to Examples 5 and 6 may contribute to improving wettability, Examples 5 and 6 may have both excellent fluidity and excellent wettability. On the other hand, the cast iron according to Comparative Example 4 has excellent fluidity but poor wettability, so that it is difficult to manufacture a structure having micro-channels of 2 mm or less.

[0105] Referring to FIG. 12 and Table 5, it can be seen that the high-entropy alloys according to Examples 5 and 6 have excellent hardness, excellent wear resistance, and excellent castability. In particular, it can be seen that the high-entropy alloy according to Example 5 has very excellent hardness, wear resistance, and castability characteristics. Further, referring to FIG. 13(b) and Table 5, it can be seen that the high entropy alloy according to Comparative Example 5 showed excellent hardness and wear resistance, but had low fillability and uneven wear. Since the high-entropy alloy according to Comparative Example 5 has a very hard characteristic with a small strain, a large amount of oxidation of aluminum occurs when manufactured by atmospheric casting, so that many bubbles and cracks may occur inside the cast product. Further, the cast iron according to Comparative Example 4 has relatively low fillability and does not have high entropy. Furthermore, it can be seen that the high entropy alloy according to Comparative Example 6 has low fillability, low hardness, and very irregular wear.

[0106] The above-described features, structures, effects, etc. are included in at least one embodiment of the present disclosure, and are not necessarily limited to only one embodiment. Furthermore, the features, structures, effects, etc. illustrated in each embodiment may be combined or modified for other embodiments by those of ordinary skill in the art to which the embodiments belong. Accordingly, the contents related to such combinations and modifications should be interpreted as being included in the scope of the present disclosure.

Claims

1. A high-entropy alloy having an iron-rich phase and a copper-rich phase, wherein the high-entropy alloy comprises a common complete solid solution metal that is completely solid-solved in iron and copper respectively.
2. The high-entropy alloy of claim 1, wherein the common complete solid solution metal comprises nickel (Ni).
3. The high-entropy alloy of claim 1, further comprising:
a melting point lowering element for lowering a melting point of the high-entropy alloy.
4. The high-entropy alloy of claim 3, wherein the melting point lowering element comprises at least one of carbon, silicon, phosphorus, and manganese.
5. The high-entropy alloy of claim 1, wherein the high-entropy alloy further comprises at least one of aluminum, manganese, and chromium.
6. The high-entropy alloy of claim 1, wherein the high-entropy alloy comprises 15 to 80 at% iron, 1 to 30 at% copper,

1 to 20 at% nickel, 5 to 20 at% aluminum, 0 to 20 at% manganese, 0 to 15 at% chromium, 0 to 5 at% carbon, 0 to 2 at% silicon, 0 to 2 at% phosphorus, and other unavoidable impurities.

7. The high-entropy alloy of claim 1, wherein a content of the copper in the iron-rich phase ranges from 5 to 30 at%.

8. The high-entropy alloy of claim 1, wherein the iron-rich phase is contained in a larger volume ratio than the copper-rich phase to be present as a main phase, and the copper-rich phase is partially present.

9. A method for manufacturing a high-entropy alloy, comprising:

an iron melting step of melting an iron-containing material including a melting point lowering element and iron to form a molten metal;

a high melting point material melting step of putting a high melting point element that has a melting point higher than that of the iron-containing material into the molten metal, and melting the high melting point element;

a copper melting step of putting copper into the molten metal, and then melting the copper; and

a low melting point material melting step of putting a low melting point material that has a melting point lower than that of the copper, and then melting the low melting point material.

10. The method of claim 9, wherein the iron-containing material comprises pig iron.

11. The method of claim 9, wherein the melting point lowering element comprises at least one of carbon, silicon, phosphorus, and manganese.

12. The method of claim 9, wherein at least two of a first melting temperature of the iron melting step, a second melting temperature of the high melting point material melting step, a third melting temperature of the copper melting step, and a fourth melting temperature of the low melting point material melting step have different temperatures.

13. The method of claim 12, wherein the second melting temperature is higher than the first melting temperature, the third melting temperature is lower than the second melting temperature, and the fourth melting temperature is lower than the third melting temperature.

14. The method of claim 9, wherein the high-entropy alloy comprises a common complete solid solution metal that is completely solid-solved in iron and copper respectively.

15. The method of claim 9, wherein the high melting point material comprises at least one of nickel and chromium.

16. The method of claim 9, wherein the low melting point material comprises aluminum.

17. The method of claim 16, wherein, in the low melting point material melting step, aluminum ingot is pushed into a bottom portion of the molten metal to be melted.

18. A method for manufacturing a high-entropy alloy, comprising:

a basic step of putting a plurality of materials including iron, copper, and a common complete solid solution metal that is completely solid-solved in iron and copper respectively;

a step of forming inert gas atmosphere after vacuum; and

a melting step of melting the plurality of materials.

19. The method of claim 18, wherein the plurality of materials further comprise at least one of carbon, silicon, phosphorus, aluminum, manganese, and chromium, and the common complete solid solution metal comprises nickel.

20. The method of claim 18, wherein the iron comprises pig iron or pure iron.

FIG. 1

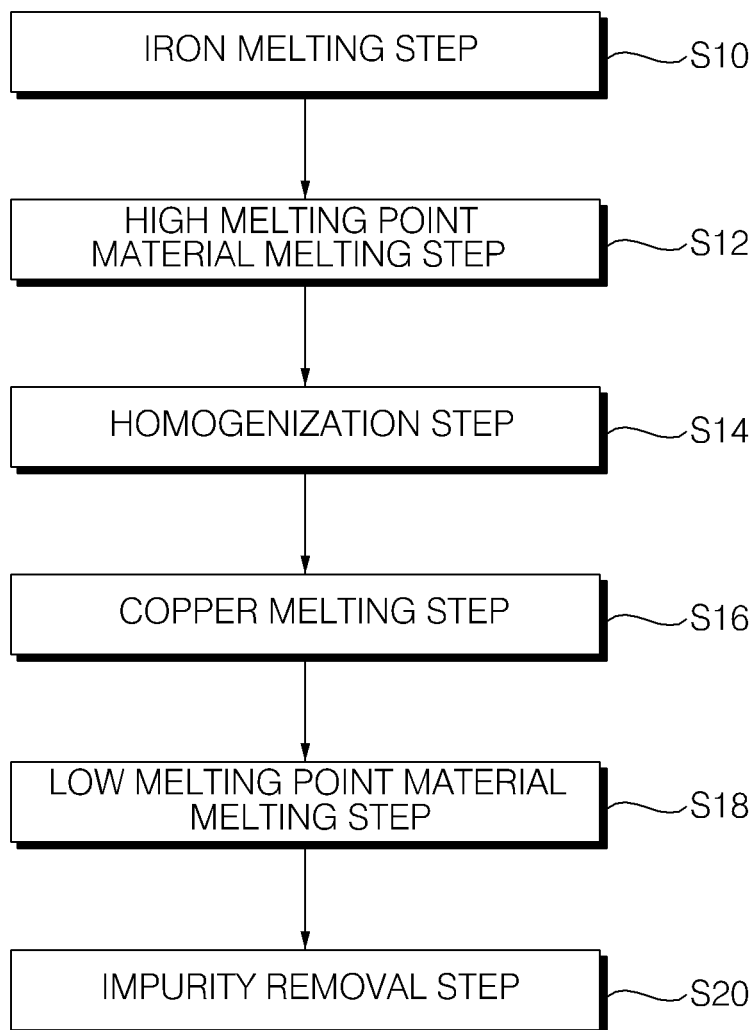


FIG. 2

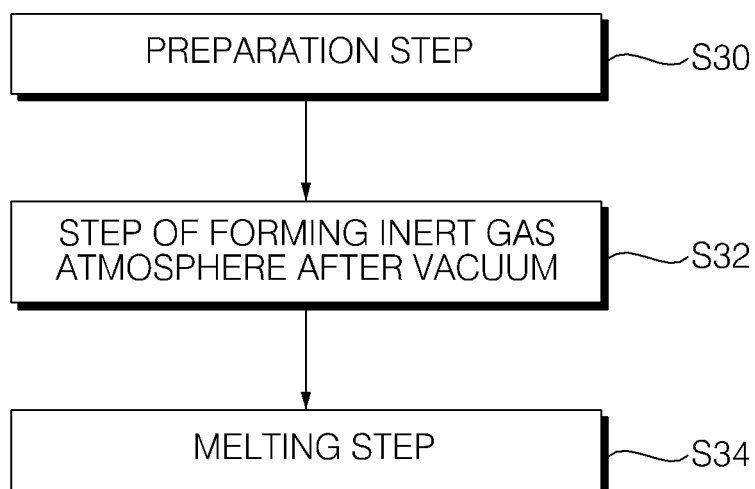


FIG. 3

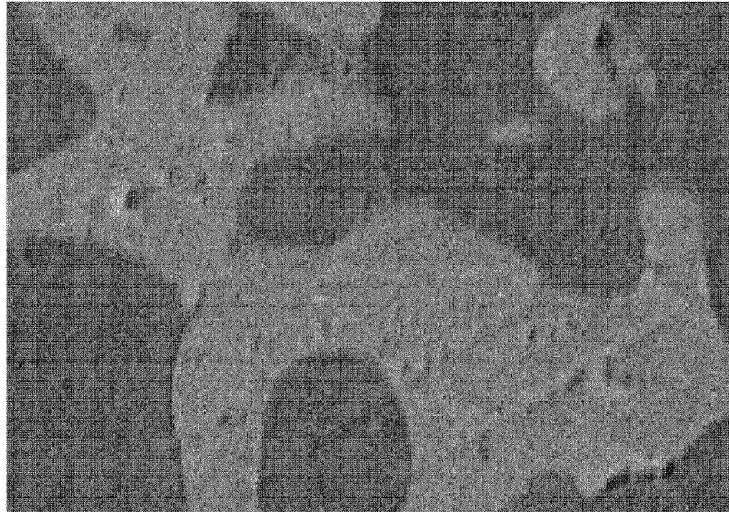
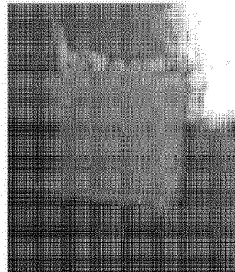
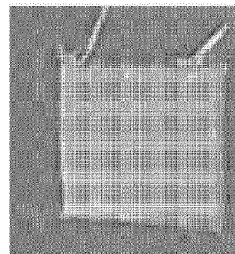


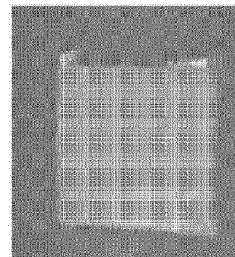
FIG. 4



(a)



(b)



(c)

FIG. 5

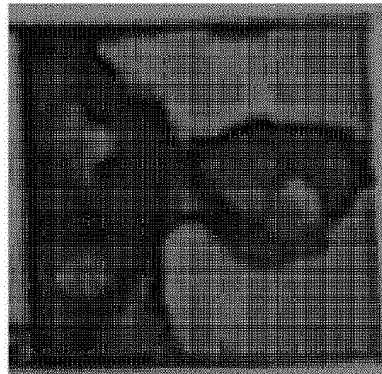
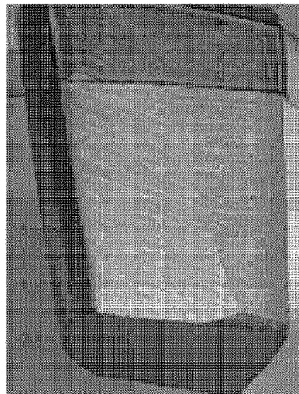
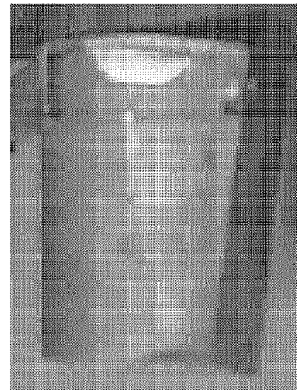


FIG. 6

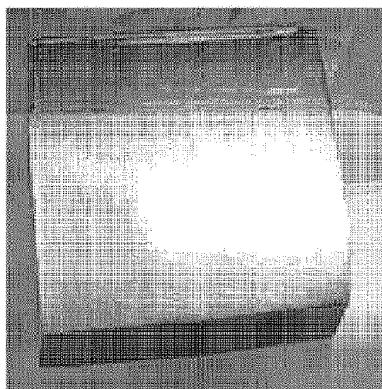


(a)

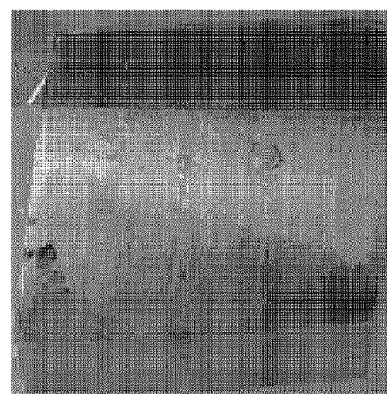


(b)

FIG. 7



(a)



(b)

FIG. 8

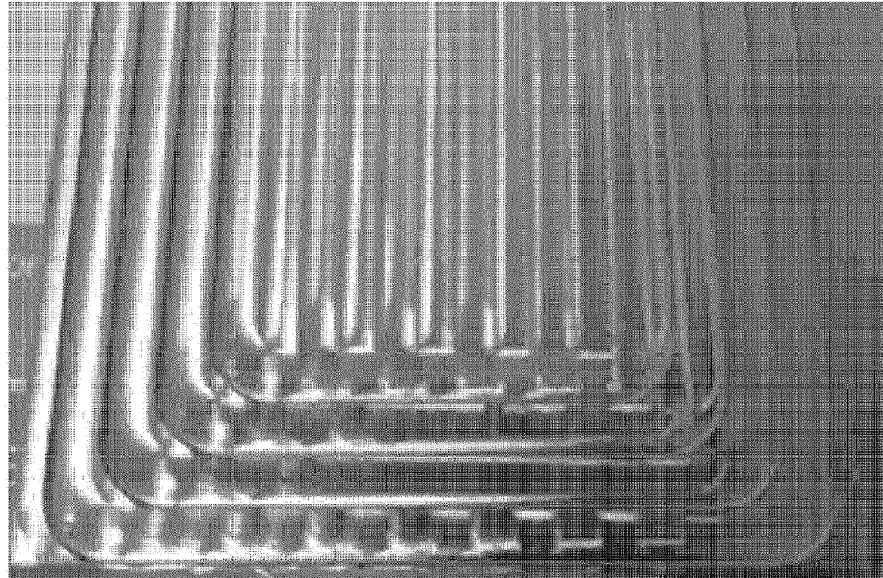


FIG. 9

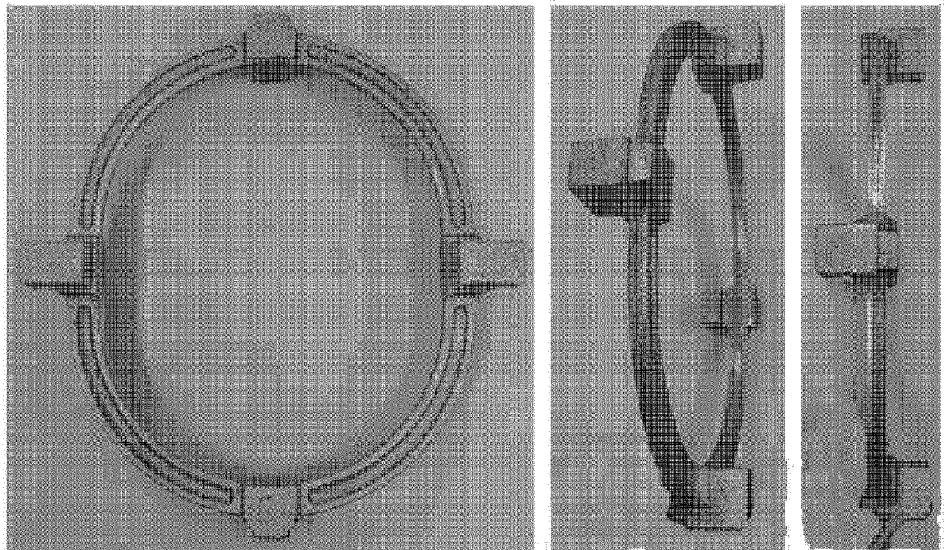
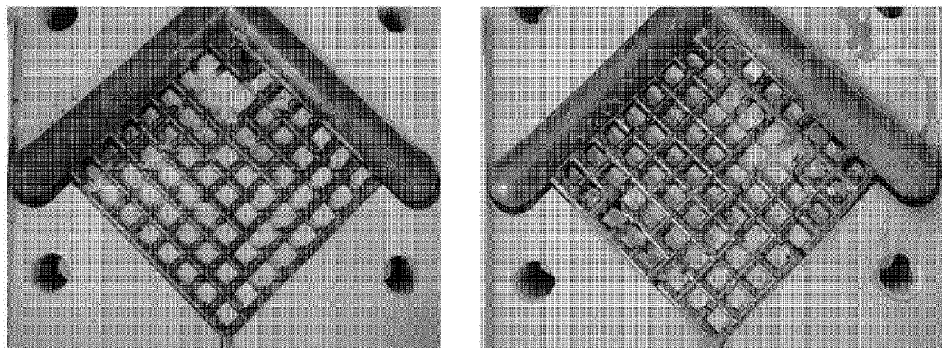


FIG. 10



(a)

(b)

FIG. 11

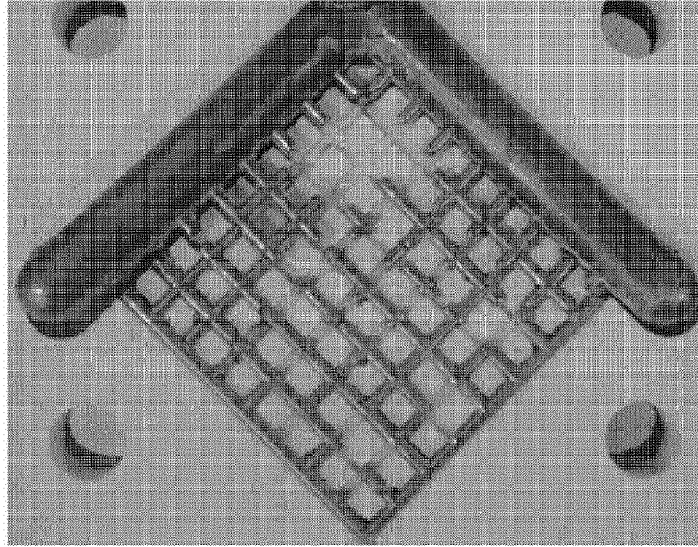
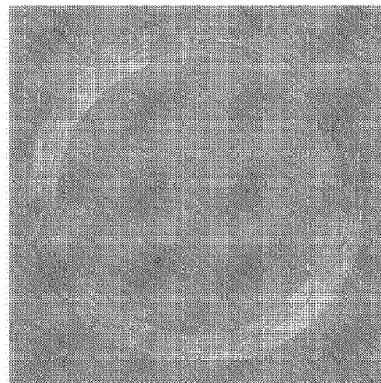
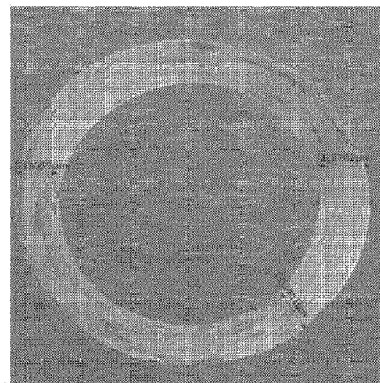


FIG. 12

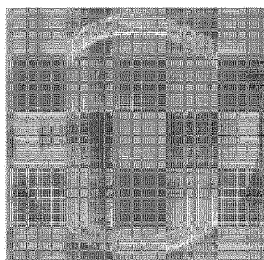


(a)

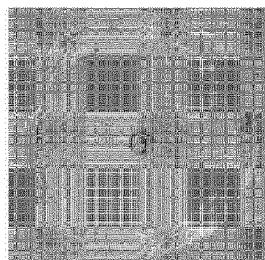


(b)

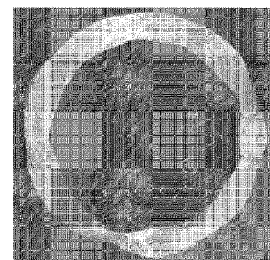
FIG. 13



(a)



(b)



(c)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2020/006209

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/42(2006.01)i; C22C 38/58(2006.01)i; C22C 1/02(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/42(2006.01); B22F 9/04(2006.01); C22C 1/02(2006.01); C22C 1/04(2006.01); C22C 30/02(2006.01);
C22C 9/02(2006.01); C22F 1/16(2006.01)

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

Korean utility models and applications for utility models: IPC as above

Japanese utility models and applications for utility models: IPC as above

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

eKOMPASS (KIPO internal) & keywords: 엔트로피 합금(entropy alloy), 상(phase), 철-리치상(Fe-rich phase), 구리-리치상
(Cu-rich phase), 니켈(Nickel), 내부식성(corrosion resistance), 구조성(castability), 가공성(processability)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2017-0275745 A1 (THE INDUSTRY & ACADEMIC COOPERATION IN CHUNGNAM NATIONAL UNIVERSITY (IAC)) 28 September 2017 (2017-09-28) See paragraphs [0026]-[0038] and claims 1-2 and 6.	1-5,7-15,18-20
Y		6,16-17
Y	KR 10-2020-0045432 A (SEOUL NATIONAL UNIVERSITY R&DB FOUNDATION) 04 May 2020 (2020-05-04) See paragraphs [0081]-[0088] and claims 1-2 and 5-12.	6,16-17
A	KR 10-1928329 B1 (KOOKMIN UNIVERSITY INDUSTRY ACADEMY COOPERATION FOUNDATION) 12 December 2018 (2018-12-12) See paragraphs [0033]-[0041] and claim 1.	1-20
A	CN 110541104 A (SOUTH CHINA UNIVERSITY OF TECHNOLOGY) 06 December 2019 (2019-12-06) See abstract and claims 1-2.	1-20

☒ 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

“D” document cited by the applicant in the international application

“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

19 February 2021

Date of mailing of the international search report

22 February 2021

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208

Facsimile No. +82-42-481-8578

Authorized officer

Telephone No.

Form PCT/ISA/210 (second sheet) (July 2019)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2020/006209**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2020-0006906 A (LG ELECTRONICS INC. et al.) 21 January 2020 (2020-01-21) See paragraphs [0025]-[0035] and claims 3 and 5.	1-20

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2020/006209

5

10

15

20

25

30

35

40

45

50

55

Patent document cited in search report				Publication date (day/month/year)		Patent family member(s)		Publication date (day/month/year)	
US	2017-0275745	A1		28 September 2017		KR	10-1744102	B1	20 June 2017
						US	10570491	B2	25 February 2020
						US	2020-0149144	A1	14 May 2020
KR	10-2020-0045432	A		04 May 2020		WO	2020-085755	A1	30 April 2020
KR	10-1928329	B1		12 December 2018		KR	10-2018-0097909	A	03 September 2018
CN	110541104	A		06 December 2019		None			
KR	10-2020-0006906	A		21 January 2020		WO	2020-013524	A1	16 January 2020