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(54) **HIGH-ENTROPY ALLOY AND MANUFACTURING METHOD THEREFOR**

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(57) **ABSTRACT**

The present disclosure relates to a high-entropy alloy and a manufacturing method therefor, and in particular, a high-entropy alloy and a manufacturing method therefor that comprises a multi-element alloy matrix and Cu, and comprises an alloy having a face-centered cubic (FCC)-based phase, such that the high-entropy alloy may have greater hardness and strength than an existing transition metal alloy while maintaining a FCC-based single phase, and has high lubricity.

HIGH-ENTROPY ALLOY AND MANUFACTURING METHOD THEREFOR

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority under 35 U.S.C. § 119 to Korean Application No. 10-2022-0126332 filed on Oct. 4, 2022, whose entire disclosure is hereby incorporated by reference.

BACKGROUND

1. Field

[0002] Disclosed herein are a high-entropy alloy and a manufacturing method therefor, and in particular, a high-entropy alloy having high strength, hardness and lubricity and a manufacturing method therefor.

2. Background

[0003] High-entropy alloys (HEAs) are multi-element alloys that are obtained by alloying 5 or more elements at a similar ratio, rather than a major element constituting alloys. Intermetallic compounds or interphases are not formed in HEAs since the entropy of mixing in the alloys is high, and HEAs are metallic materials having a single phase tissue such as a face-centered cubic (FCC) or a body-centered cubic (BCC).

[0004] In designing a high-entropy alloy, two important factors include composition ratios of elements constituting an alloy and configurational entropy of an alloy group.

[0005] As mentioned above, the first important factor is a composition ratio of a high-entropy alloy. A high-entropy alloy needs to be comprised of at least 5 or more elements, and a composition ratio of each element constituting the alloy is defined as 5 to 35 at %. Additionally, in the case where another element is added in addition to a major element constituting a high-entropy alloy at a time of manufacturing the high-entropy alloy, another element needs to be added at 5 at % or less.

[0006] Alloys are ordinarily categorized into high-entropy alloys, medium-entropy alloys (MEAs) and low-entropy alloys (LEAs), depending on configurational entropy (Sconf) based on the composition of alloy elements.

[0007] However, alloy elements included in an alloy group that is being studied currently are very expensive, and heavy alloy elements are mainly used for high-entropy and medium-entropy alloys, making it hard to commercialize high-entropy and medium-entropy alloys. In recent years, research has been performed into a lightweight high-entropy alloy that is manufactured based on a combination of lightweight alloy elements. However, solid solubility among lightweight alloy elements is low, and in a case where an alloy element is added in almost the same proportion, based on the definition of a high-entropy alloy, an intermetallic compound is formed in a high-entropy alloy, limiting plastic deformation of the alloy, degrading workability and making it hard to commercialize the alloy.

[0008] To commercialize high-entropy and medium-entropy alloys, price competitiveness and excellent mechanical properties need to be realized based on an adjustment of alloy elements.

[0009] High-entropy and medium-entropy alloys described above are used for parts of a superprecision machine such as a micro gear as well as turbines, compressors, gear boxes and the like used in the aerospace, aviation, vehicle, vessel and heavy equipment areas.

[0010] Importantly, the surfaces of portions affected by a friction and wear among the parts need to ensure high hardness and lubricity. To this end, a new material needs to be developed to ensure basic mechanical properties such as hardness, fracture toughness and the like of an existing material applied to the parts and to adjust high functionality property in accordance with a usage environment.

[0011] Further, the surface of a bearing of a compressor to which a mater alloy for coating is mainly applied needs to have basic properties such as high rigidity and high hardness, and low friction coefficient and high lubricity that conceptually conflict with the basic properties.

[0012] To ensure the above-described properties, composite materials and composite structuralization are ordinarily used, and a metallic material is developed to include a crystalline strengthened phase as/in a high hardness-high corrosion resistance non-crystalline matrix. However, manufacturing conditions for forming non-crystals are not appropriate for ordinary mass production, and a forming process for a complex part is hardly performed.

DETAILED DESCRIPTION

[0013] The above-described aspects, features, and advantages are specifically described hereinafter with reference to accompanying drawings such that one having ordinary skill in the art to which embodiments pertain can embody the technical spirit easily. Hereinafter, description of known technologies in relation to the subject matter is omitted if it is deemed to make the gist unnecessarily vague. Hereinafter, the embodiments are specifically described with reference to the accompanying drawings.

[0014] Throughout the disclosure, each component can be provided a single one or a plurality of ones, unless stated to the contrary.

[0015] The singular forms "a", "an" and "the" are intended to include the plural forms as well, unless explicitly indicated otherwise. It is to be further understood that the terms "comprise" or "include" and the like, set forth herein, are not interpreted as necessarily including all the stated components or steps but can be interpreted as excluding some of the stated components or steps or can be interpreted as including additional components or steps.

[0016] Hereinafter, a high-entropy alloy and a manufacturing method therefor according to the present disclosure are described.

High-Entropy Alloy

[0017] Provided is a novel alloy having high lubricity as well as high hardness and high strength, by doping Cu to an existing alloy and adjusting a doping amount, to improve the low strength of an FCC-based high-entropy alloy and provide high lubricity to the FCC-based high-entropy alloy.

[0018] The high-entropy alloy according to the present disclosure comprises a multi-element alloy matrix and Cu, and the multi-element alloy matrix comprises three or more sorts among Cr, Co, Ni and Mo, and an alloy having a face-centered cubic (FCC)-based single phase.

[0019] Like an existing high-entropy alloy, the high-entropy alloy according to the present disclosure comprises a multi-element alloy base, and the alloy matrix comprises

three or more sorts among Cr, Co, Ni and Mo. Additionally, the alloy according to the present disclosure comprises Cu as well as the alloy base. Accordingly, the alloy in the present disclosure experiences a severe lattice distortion, maintains a FCC-based single phase, and has increased hardness and strength. Further, the alloy in the present disclosure exhibits low friction and high lubricity.

[0020] In particular, the component Cu performs a lubrication operation, in a soft phase that is a typical metal lubrication phase, even at high temperature. In an alloy, the component Cu exhibits its properties, based on precipitation. Mostly, the element Cu has low solid solubility in an alloy, and is precipitated in a Cu-rich phase of the matrix and another composition/component. However, the element Cu may decrease the hardness and strength of an alloy and not be ordinarily applied to a high-entropy alloy.

[0021] For the high-entropy alloy in the present disclosure, Cu is applied to three or more sorts of the multi-element alloy base, among Cr, Co, Ni and Mo, such that the high-entropy alloy exhibits excellent hardness, strength and lubricity.

[0022] Specifically, the high-entropy alloy in an embodiment may be expressed as chemical formula 1 described hereafter, and comprise an alloy having a face-centered cubic (FCC)-based single phase.

$$Cr_aCo_bNi_cCu_x \quad \text{[Chemical formula 1]}$$

[0023] (In chemical formula 1 described above, a+b+c+x=1, and $O<x\leq 0.2$ are satisfied.)

[0024] Additionally, x described above may satisfy $0.02\leq x\leq 0.2$, preferably.

[0025] Further, the high-entropy alloy in one embodiment may be expressed as chemical formula 2 described hereafter and comprise an alloy having a face-centered cubic (FCC)-based single phase.

$$Mo_aCo_bNi_cCu_x \quad \text{[Chemical formula 2]}$$

[0026] (In chemical formula 2 described above, a+b+c+x=1, and $O<x\leq 0.2$ are satisfied.)

[0027] Preferably, x described above may satisfy $0.1\leq x\leq 0.2$.

Manufacturing Method for High-Entropy Alloy

[0028] The manufacturing method for a high-entropy alloy according to the present disclosure comprises manufacturing a mixture powder in which an alloy matrix element and a Cu powder are mixed; heating and dissolving the mixture power, and casting the mixture powder in a predetermined form; rolling the cast alloy and manufacturing an alloy material; and thermally treating the alloy material and manufacturing an alloy, wherein the alloy matrix element comprises three or more sorts among Cr, Co, Ni and Mo, and the alloy has a face-centered cubic (FCC)-based single phase.

[0029] The manufacturing method for a high-entropy alloy according to the present disclosure comprises manufacturing a mixture powder in which an alloy matrix element and a Cu powder are mixed.

[0030] The multi-element alloy matrix comprises three or more sorts among Cr, Co, Ni and Mo. A preferable atomic % of the alloy is described above.

[0031] Then the manufacturing method for a high-entropy alloy according to the present disclosure comprises heating and dissolving the mixture power, and casting the mixture powder in a predetermined form. The casting method is not limited, and the casting process may be performed in a way that a melting pot is charged with a material.

[0032] Further, the manufacturing method for a high-entropy alloy according to the present disclosure may comprise milling and mechanically alloying the mixture powder and forming a mechanically alloyed powder, before the casting process.

[0033] Then the manufacturing method for a high-entropy alloy according to the present disclosure comprises rolling the cast alloy and manufacturing an alloy material. Preferably, the rolling process may comprise hot rolling and cold rolling. Preferably, the cast alloy may be rolled such that a reduction ratio may be 60 to 80%.

[0034] Then the manufacturing method for a high-entropy alloy according to the present disclosure comprises thermally treating the alloy material and manufacturing an alloy. Herein, the quality of the alloy may become homogeneous, based on the thermal treatment.

[0035] The thermally treating process may be performed in a vacuum atmosphere, an inert gas atmosphere, an oxygen atmosphere, or an atmosphere including at least any one of nitrogen, boron and carbon.

[0036] Further, the thermally treating process may be performed at 200° C. to 1300° C. for 1 to 24 hours, preferably, at 900° C. to 1000° C. for 6 hours or greater.

[0037] The high-entropy alloy manufactured based on the manufacturing method in the present disclosure may comprise the above-described alloy.

[0038] Hereinafter, the subject matter of the present disclosure is described more specifically, with reference to preferred embodiments.

Embodiment

1. Manufacturing of Embodiments and Comparative Example

[0039] An alloy matrix element and a Cu powder were mixed at ratios in the following table, to manufacture a mixture powder. Each pure element was prepared in the form of a pellet of 10 mm or less and of purity of 99.5% or greater.

[0040] A melting pot was charged with the pure element, and the pure element was heated and dissolved at 1550° C., and then a dissolved alloy was manufactured as an ingot, in a zirconia melting pot. Pressure in the solidification process was maintained at about 2.5 bar. The ingot was hot-rolled at 900 to 1100° C., at a reduction ratio of 60%, and then air-cooled (air quenched). Then a cold-rolled plate was thermally treated. All the above-described thermally treating processes were performed at 1100° C. for 6 hours in an inert gas (Ar) atmosphere.

TABLE 1

	Cr (at %)	Mo (at %)	Fe (at %)	Co (at %)	Ni (at %)	Cu (at %)
Comparative example 1	33.33	0	0	33.33	33.33	0
Embodiment 1	10	0	0	34	54	2
Embodiment 2	10	0	0	32.5	52.5	5
Embodiment 3	10	0	0	30	50	10
Embodiment 4	10	0	0	10	60	20
Embodiment 5	0	5	0	42.5	42.5	10
Embodiment 6	0	5	0	37.5	37.5	10

2. Evaluation Test

[0041] Test results of the HV hardness and tensile strength of the manufactured alloys are shown in the following table.

TABLE 2

	HV hardness	YS (MPa)	UTS (MPa)	EL (%)	Friction coefficient
Comparative example 1	153.0 ± 3.0	275.0	630.0	83.8	0.671
Embodiment 1	122.0 ± 5.0	174.0	509.0	51.0	0.381
Embodiment 2	136.0 ± 5.0	196.0	522.0	52.3	0.379
Embodiment 3	141.3 ± 5.5	217.0	521.0	46.4	0.372
Embodiment 4	149.8 ± 5.2	242.0	562.0	25.8	0.383
Embodiment 5	160.0 ± 5.2	249.0	702.0	41.8	0.422
Embodiment 6	211.0 ± 5.2	563.0	707.0	25.1	0.402

[0042] Referring to table 2, the hardness and strength of embodiments 1 to 4 including Cu are slightly less than those of an alloy including no Cu (comparative example 1), but the friction coefficient of embodiments 1 to 4 is much less than that of comparative example 1. However, the hardness and strength of embodiments 5 and 6 including Mo are greater than those of comparative example 1, and the friction coefficient of embodiments 1 to 4 is less than that of comparative example 1.

[0043] As described above, the high-entropy alloy according to the present disclosure has excellent hardness and strength like an existing alloy, and has high lubricity unlike an existing alloy.

[0044] The embodiments are described above with reference to a number of illustrative embodiments thereof. However, embodiments are not limited to the embodiments and drawings set forth herein, and numerous other modifications and embodiments can be drawn by one skilled in the art within the technical scope of the disclosure. Further, the effects and predictable effects based on the configurations in the disclosure are to be included within the range of the disclosure.

Technical Problems

[0045] The objective of the present disclosure is to provide a novel high-entropy alloy exhibiting high strength, high hardness and high lubricity.

[0046] The objective of the present disclosure is to provide a novel high-entropy alloy to which Cu is added, ensuring low friction coefficient and high lubricity.

[0047] The objective of the present disclosure is to provide a manufacturing method of a high-entropy alloy.

[0048] Aspects according to the present disclosure are not limited to the above ones, and other aspects and advantages that are not mentioned above can be clearly understood from the following description and can be more clearly understood from the embodiments set forth herein. Additionally, understandably, the aspects and advantages in the present disclosure are embodied via means and combinations thereof that are described in the appended claims.

Technical Solutions

[0049] In a high-entropy alloy according to the present disclosure, Cu is added to a multi-element alloy matrix to maintain a face-centered cubic (FCC)-based single phase and ensure high hardness, strength and lubricity.

[0050] Specifically, the high-entropy alloy according to the present disclosure comprises a multi-element alloy matrix and Cu, and the multi-element alloy matrix comprises three or more sorts among Cr, Co, Ni and Mo, and comprises an alloy having a face-centered cubic (FCC)-based single phase.

[0051] Preferably, the high-entropy alloy in one embodiment may be expressed as chemical formula 1 described hereafter.

$$Cr_aCo_bNi_cCu_x \quad \text{[Chemical formula 1]}$$

[0052] (In chemical formula 1, a+b+c+x=1, and $O<x\leq 0.2$ are satisfied.)

[0053] Preferably, x above may satisfy $0.02\leq x\leq 0.2$.

[0054] Further, the high-entropy alloy in one embodiment may be expressed as chemical formula 2 described hereafter.

$$Mo_aCo_bNi_cCu_x \quad \text{[Chemical formula 2]}$$

[0055] (In chemical formula 2 described above, a+b+c+x=1, and $O<x\leq 0.2$ are satisfied.)

[0056] Preferably, x above may satisfy $0.1\leq x\leq 0.2$.

[0057] A manufacturing method for a high-entropy alloy in one embodiment comprises manufacturing a mixture powder in which an alloy matrix element and a Cu powder are mixed; heating and dissolving the mixture power, and casting the mixture powder in a predetermined form; rolling the cast alloy and manufacturing an alloy material; and thermally treating the alloy material and manufacturing an alloy, wherein the alloy matrix element comprises three or more sorts among Cr, Co, Ni and Mo, and the alloy has a face-centered cubic (FCC)-based single phase.

Advantageous Effects

[0058] According to the present disclosure, a novel high-entropy alloy ensuring improvement in mechanical properties at room temperature and high temperature may be provided.

[0059] The high-entropy alloy in the present disclosure has greater strength than an existing transition metal alloy, while maintaining an FCC-based single phase.

[0060] Additionally, the high-entropy alloy in the present disclosure has high strength, hardness and lubricity.

[0061] Further, the high-entropy alloy in the present disclosure ensures low friction coefficient and high lubricity.

[0062] Furthermore, the manufacturing method of a high-entropy alloy in the present disclosure may involve changing the microstructure of the high-entropy alloy, in a homogenization process based on thermal treatment, to maximize the strength, hardness and lubricity of the high-entropy alloy.

[0063] Specific effects are described along with the above-described effects in the section of detailed description.

[0064] It will be understood that when an element or layer is referred to as being "on" another element or layer, the element or layer can be directly on another element or layer or intervening elements or layers. In contrast, when an element is referred to as being "directly on" another element or layer, there are no intervening elements or layers present. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0065] It will be understood that, although the terms first, second, third, etc., may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer or section from another region, layer or section. Thus, a first element, component, region, layer or section could be termed a second element, component, region, layer or section without departing from the teachings of the present invention.

[0066] Spatially relative terms, such as "lower", "upper" and the like, may be used herein for ease of description to describe the relationship of one element or feature to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation, in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "lower" relative to other elements or features would then be oriented "upper" relative to the other elements or features. Thus, the exemplary term "lower" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[0067] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0068] Embodiments of the disclosure are described herein with reference to cross-section illustrations that are schematic illustrations of idealized embodiments (and intermediate structures) of the disclosure. As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, embodiments of the disclosure should not be construed as limited to the particular shapes of regions illustrated herein but are to include deviations in shapes that result, for example, from manufacturing.

[0069] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0070] Any reference in this specification to "one embodiment," "an embodiment," "example embodiment," etc., means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The appearances of such phrases in various places in the specification are not necessarily all referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with any embodiment, it is submitted that it is within the purview of one skilled in the art to effect such feature, structure, or characteristic in connection with other ones of the embodiments.

[0071] Although embodiments have been described with reference to a number of illustrative embodiments thereof, it should be understood that numerous other modifications and embodiments can be devised by those skilled in the art that will fall within the spirit and scope of the principles of this disclosure. More particularly, various variations and modifications are possible in the component parts and/or arrangements of the subject combination arrangement within the scope of the disclosure, the drawings and the appended claims. In addition to variations and modifications in the component parts and/or arrangements, alternative uses will also be apparent to those skilled in the art.

What is claimed is:

1. A high-entropy alloy, comprising:

a multi-element alloy matrix and Cu,

wherein the multi-element alloy matrix includes three or more elements among Cr, Co, Ni and Mo, and

the high-entropy alloy has a face-centered cubic (FCC)-based single phase.

2. The high-entropy alloy of claim **1**, wherein the multi-element alloy matrix is expressed by Chemical Formula 1 as follows:

$$Cr_aCo_bNi_cCu_x, \quad \text{[Chemical formula 1]}$$

wherein the Chemical Formula 1 is satisfied by $a+b+c+x=1$ and $0<x\leq 0.2$.

3. The high-entropy alloy of claim **2**, wherein in the Chemical Formula 1 x satisfies $0.02\leq x\leq 0.2$.

4. The high-entropy alloy of claim **1**, wherein the multi-element alloy matrix is expressed by Chemical Formula 2 as follows:

$$Mo_aCo_bNi_cCu_x, \quad \text{[Chemical formula 2]}$$

wherein the Chemical Formula 2 is satisfied by $a+b+c+x=1$ and $0<x\leq 0.2$.

5. The high-entropy alloy of claim **4**, wherein in the Chemical Formula 2 x satisfies $0.1\leq x\leq 0.2$.

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

providing a mixture powder by mixing a multi-element alloy matrix and a Cu powder;

heating the mixture power, and casting the heated mixture powder to provide a cast alloy;

rolling the cast alloy and providing an alloy material; and

thermally treating the alloy material and providing the high-entropy alloy,

wherein the multi-element alloy matrix includes three or more elements among Cr, Co, Ni and Mo, and the high-entropy alloy has a face-centered cubic (FCC)-based single phase.

7. The manufacturing method of claim **6**, wherein the thermally treating is performed in a vacuum atmosphere, an inert gas atmosphere, an oxygen atmosphere, or an atmosphere including at least one of nitrogen, boron and carbon.

8. The manufacturing method of claim **6**, wherein the thermally treating is performed at 200° C. to 1300° C. for 1 to 24 hours.

9. The manufacturing method of claim **6**, wherein the multi-element alloy matrix is expressed by Chemical Formula 1 as follows:

$$Cr_aCo_bNi_cCu_x, \quad \text{[Chemical formula 1]}$$

wherein the Chemical Formula 1 is satisfied by a+b+c+x=1 and $O<x\leq 0.2$.

10. The manufacturing method of claim **9**, wherein the Chemical Formula 1 is satisfied by x being $0.02\leq x\leq 0.2$.

11. The manufacturing method of claim **6**, wherein the multi-element matrix element is expressed by the following Chemical Formula 2:

$$Mo_aCo_bNi_cCu_x, \quad \text{[Chemical formula 2]}$$

wherein the Chemical Formula 2 is satisfied by a+b+c+x=1 and $O<x\leq 0.2$.

12. The manufacturing method of claim **11**, wherein the Chemical Formula 2 is satisfied by x being $0.1\leq x\leq 0.2$.

13. A method of producing a high-entropy alloy, comprising:

mixing a multi-element alloy matrix and Cu to provide a mixture powder;

heating the mixture power;

rolling the heated mixture powder and providing an alloy material; and

heating the alloy material and providing the high-entropy alloy,

wherein the multi-element alloy matrix includes three or more elements among Cr, Co, Ni and Mo, and the high-entropy alloy has a face-centered cubic (FCC)-based single phase.

14. The method of claim **13**, wherein the heating the alloy material is performed in a vacuum atmosphere, an inert gas atmosphere, an oxygen atmosphere, or an atmosphere including at least one of nitrogen, boron and carbon.

15. The method of claim **13**, wherein the heating the alloy material is performed at 200° C. to 1300° C. for 1 to 24 hours.

16. The method of claim **13**, wherein the multi-element alloy matrix is expressed by Chemical Formula 1 as follows:

$$Cr_aCo_bNi_cCu_x, \quad \text{[Chemical formula 1]}$$

wherein the Chemical Formula 1 is satisfied by a+b+c+x=1 and $O<x\leq 0.2$.

17. The method of claim **16**, wherein the Chemical Formula 1 is satisfied by x being $0.02\leq x\leq 0.2$.

18. The method of claim **13**, wherein the multi-element matrix element is expressed by the following Chemical Formula 2:

$$Mo_aCo_bNi_cCu_x, \quad \text{[Chemical formula 2]}$$

wherein the Chemical Formula 2 is satisfied by a+b+c+x=1 and $O<x\leq 0.2$.

19. The method of claim **18**, wherein the Chemical Formula 2 is satisfied by x being $0.1\leq x\leq 0.2$.

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