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(54) **LIGHTWEIGHT HIGH-ENTROPY ALLOY HAVING HIGH STRENGTH AND HIGH PLASTICITY AND PREPARATION METHOD THEREFOR**

(57) The invention relates to a lightweight high-entropy alloy with high strength and high plasticity and a preparation method thereof, belonging to the fields of metal materials and preparation thereof. The high-entropy alloy is mainly composed of Ti, Zr, V, Nb and M, wherein M is one or more of Al, Hf, Cr, Fe, Mg, Be, Li, Mo, Co, Ni, Si, B, O and N. By regulating contents of all the elements, the high-entropy alloy has low density, high strength and high plasticity so as to have a huge application potential in the field of engineering. Moreover, the preparation method of the high-entropy alloy is easy to operate as well as safe and reliable, the adopted raw materials are nontoxic and harmless, and the high-entropy alloy is economical and practical.

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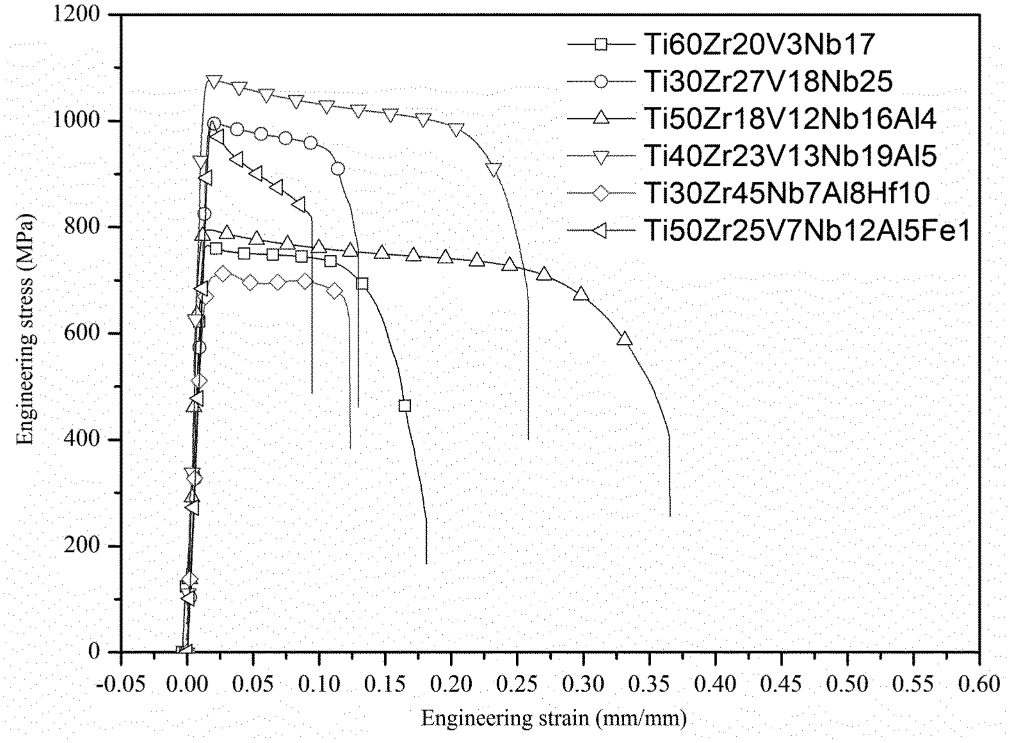
Ti60Zr20V3Nb17
Ti30Zr27V18Nb25
Ti50Zr18V12Nb16Al4
Ti40Zr23V13Nb19Al5
Ti30Zr45Nb7Al8Hf10
Ti50Zr25V7Nb12Al5Fe1
Engineering stress (MPa)
Engineering strain (mm/mm)
0
200
400
600
800
1000
1200
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60

Fig. 8

## Description

## TECHNICAL FIELD

**[0001]** The present invention relates to a lightweight high-entropy alloy with high strength and high plasticity and a preparation method thereof, belonging to the fields of metal materials and preparation thereof.

## BACKGROUND

**[0002]** A high-entropy alloy is an alloy formed by combining five or more elements in an approximate equi-atomic ratio and is also referred to as a multi-principal-element and high-irregularity alloy. Due to a multi-principal-element effect (a high-entropy effect, a lattice distortion effect, a lagged diffusion effect and a cocktail effect), the high-entropy alloy shows a metallurgical-physical effect mechanism different from that of traditional alloy and further shows a series of excellent properties such as outstanding high-temperature strength, good low-temperature plasticity, good wear resistance, good corrosion resistance and excellent radiation resistance. With the development of research, the range of the high-entropy alloy is widened, elements are no longer limited to five or more than five elements, the atomic proportion also gradually deviates from an equi-atomic ratio, and the designability of the alloy is greatly improved.

**[0003]** At present, researchers generally adopt a method for adding a great number of low-density metals in first three periods to reduce the density of the high-entropy alloy, which results in the production of a great number of second phases. Although relatively low density, high hardness and high compression strength can be achieved, the plasticity is seriously sacrificed, which greatly limits the application in the engineering.

## SUMMARY

**[0004]** In view of this, the present invention provides a lightweight high-entropy alloy with high strength and high plasticity and a preparation method thereof. The high-entropy alloy has low density, high strength and high plasticity so as to have a huge application potential in the field of engineering. Moreover, the preparation method of the high-entropy alloy is easy to operate as well as safe and reliable, and the high-entropy alloy is economical and practical.

**[0005]** The purpose of the present invention is achieved through the following technical solutions.

**[0006]** Provided is a lightweight high-entropy alloy with high strength and high plasticity. The high-entropy alloy is marked as $Ti_aZr_bV_cNb_dM_x$ according to an atomic number ratio, M is one or more of Al, Hf, Cr, Fe, Mg, Be, Li, Mo, Co, Ni, Si, B, O and N, wherein $25<a\leq65$, $0<b\leq55$, $0\leq c<25$, $0<d\leq35$, $0\leq x<20$, $a+b+c+d+x=100$, and c and x cannot be 0 at the same time.

**[0007]** Further, in $Ti_aZr_bV_cNb_dM_x$, $25<a\leq60$, $15\leq b\leq50$, $0\leq c<25$, $5\leq d\leq30$, $0\leq x<20$, $a+b+c+d+x=100$, and c and x cannot be 0 at the same time.

**[0008]** Further, M is preferably one or more of Al, Hf, Cr, Fe, Mg, Be, Li, Mo, Co and Ni.

**[0009]** A preparation method of the high-entropy alloy provided by the present invention includes the following steps:

step 1, placing clean elemental raw materials Ti, Zr, V, Nb and M into a smelting furnace of which the vacuum degree is smaller than or equal to $2.5\times10^{-3}$ Pa, and filling the smelting furnace with a protective gas; then, performing smelting, and cooling an alloy liquid generated by smelting to obtain an alloy ingot; and overturning the alloy ingot, and performing repeated smelting for more than three times to ensure that components are uniform to obtain a high-entropy alloy ingot; and

step 2, sealing the high-entropy alloy ingot in an argon-filled quartz tube, performing solution treatment at the temperature of 900-1200°C, and keeping the temperature for 1-12 h to obtain the high-entropy alloy.

**[0010]** Further, purities of the elemental raw materials Ti, Zr, V, Nb and M are respectively greater than or equal to 99.7wt%.

**[0011]** Further, the smelting furnace is preferably an electric arc smelting furnace.

**[0012]** Further, the protective gas is preferably argon.

**[0013]** Beneficial effects:

(1) the high-entropy alloy of the present invention is composed of Ti, Zr, V, Nb and M, and by regulating contents of all the elements, the high-entropy alloy has the property advantages of low density, high strength and high plasticity so as to have a huge application potential in the field of engineering; and

(2) the preparation method of the present invention is easy to operate as well as safe and reliable, and the adopted raw materials are nontoxic, harmless and easily available.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0014]**

Fig. 1 is a comparison diagram of X-ray diffractometer (XRD) spectrums of high-entropy alloys prepared in Embodiments 1-6;

Fig. 2 is a metallographic diagram of a high-entropy alloy $Ti_{60}Zr_{20}V_3Nb_{17}$ prepared in Embodiment 1;

Fig. 3 is a metallographic diagram of a high-entropy alloy $Ti_{30}Zr_{27}V_{18}Nb_{25}$ prepared in Embodiment 2;

Fig. 4 is a metallographic diagram of a high-entropy alloy $Ti_{50}Zr_{18}V_{12}Nb_{16}Al_4$ prepared in Embodiment 3;

Fig. 5 is a metallographic diagram of a high-entropy alloy $Ti_{40}Zr_{23}V_{13}Nb_{19}Al_5$ prepared in Embodiment 4;

Fig. 6 is a metallographic diagram of a high-entropy alloy $Ti_{30}Zr_{45}Nb_7Al_8Hf_{10}$ prepared in Embodiment 5;

Fig. 7 is a metallographic diagram of a high-entropy alloy $Ti_{50}Zr_{25}V_7Nb_{12}Al_5Fe_1$ prepared in Embodiment 6; and

Fig. 8 is a comparison diagram of quasi-static tensile engineering stress-strain curves of the high-entropy alloys prepared in Embodiments 1-6.

## DETAILED DESCRIPTION

**[0015]** The present invention will be further described below in conjunction with the accompanying drawings and specific embodiments, wherein the methods are conventional methods if they are not especially specified, and the raw materials are commercially available if they are not especially specified.

**[0016]** In the following embodiments:

high-vacuum non-consumable electric arc smelting furnace: DHL-400 high-vacuum non-consumable electric arc smelting furnace produced by SKY Technology Development Co., Ltd, CAS (Chinese Academy of Sciences);

phase analysis: an X-ray diffractometer (XRD) spectrum of the prepared high-entropy alloy is measured by adopting a Rigaku Smartlab X-ray Diffractometer, wherein a K$\alpha$ ray on a Cu target is adopted, a working voltage is 40 kV, a working current is 110 mA, a scanning angle ranges from 20° to 90°, a scanning speed is 5°/min, a step length is 0.02°, and a measured angle error is smaller than 0.01°; and the size of a specimen measured by the XRD is 10 mm×10 mm×5 mm; and firstly, six surfaces are ground to be flat with 240# abrasive paper, and then, an irradiated surface is sequentially ground with 400# abrasive paper, 600# abrasive paper, 800# abrasive paper, 1000# abrasive paper, 1200# abrasive paper, 1500# abrasive paper, and 2000# abrasive paper;

microstructure: a microstructure of the prepared high-entropy alloy in a solution state is observed by adopting an Axio observer Aim research-grade metalloscope produced by the Deiss company in Germany, wherein the size of a metallographic specimen is 10 mm×10 mm×5 mm; and the metallographic specimen is firstly mounted by using a hot mounting press, then, is polished sequentially with 400# abrasive paper, 600# abrasive paper, 800# abrasive paper, 1000# abrasive paper, 1200# abrasive paper, 1500# abrasive paper, 2000# abrasive paper, 3000# abrasive paper, 5000# abrasive paper, and 7000# abrasive paper, and then, is polished with a silicon dioxide suspension with the particle size of 0.02 $\mu$m, and is finally soaked in a corrosive agent containing HF, $HNO_3$ and $H_2O$ in a volume ratio of 1:3:20 for 5-30 s;

density measurement: the density of the prepared high-entropy alloy is measured by adopting a hydrostatic weighing method according to the standard GB/T1423-1996; firstly, the specimen is placed in the air to be weighed, then, the specimen is placed on a lifting appliance to be weighed in water, finally, the lifting appliance is placed in water alone to be weighed, a buoyancy of the specimen in water is obtained by calculation according to the three weighed values, the volume of the specimen is calculated in combination with the water density, and the density of the alloy may be calculated according to the mass of the specimen in the air and the calculated volume, wherein the used specimen is the same as the specimen measured by XRD; and quasi-static tensile mechanical property test: an axial quasi-static tensile test at room temperature is performed by adopting a CMT4305 microcomputer electronic universal testing machine according to the standard GB/T228.1-2010, a strain rate is selected as $10^{-3}s^{-1}$, and a test specimen is a non-standard I-shaped piece with the thickness of 1.0 mm, the width of 3.14 mm, the parallel segment length of 10 mm and the gauge length of 5 mm.

### Embodiment 1

**[0017]** A lightweight high-entropy alloy $Ti_{60}Zr_{20}V_3Nb_{17}$ with high strength and high plasticity is prepared by the following steps:

step 1, elements Ti, Zr, V and Nb of which the purities are not smaller than 99.7wt% are adopted as raw materials, the raw materials are firstly polished by using a grinding wheel to remove oxide coatings on surfaces of the raw materials, and are then cleaned with anhydrous ethanol by ultrasonic oscillation, and clean raw materials with a total mass of (70±0.01) g are weighed according to an atomic percentage of Ti:Zr:V:Nb=60:20:3:17;

step 2, the weighed raw materials are sequentially placed in a water-cooled copper crucible of a high-vacuum non-consumable electric arc smelting furnace according to melting points from low to high, then, vacuumization is performed, and after the vacuum degree in the smelting furnace reaches $2.5\times10^{-3}$ Pa, and argon is filled as a protective gas; before the alloy is smelted, firstly, a pure metal titanium ingot is smelted to further reduce the content of oxygen in a furnace chamber of the smelting furnace, then, alloying smelting is performed, electromagnetic stirring is utilized for alloy homogenization during smelting, and an alloy liquid generated by smelting is cooled to obtain an alloy ingot; and the alloy ingot is overturned and is repeatedly smelted for four times to obtain a high-entropy alloy ingot; and step 3, the high-entropy alloy ingot is sealed in an argon-filled quartz tube to be subjected to solution treatment at the temperature of 900°C, and the temperature is kept for 1 h to obtain the high-entropy alloy $Ti_{60}Zr_{20}V_3Nb_{17}$.

**[0018]** It can be known from the XRD spectrum in Fig. 1 that the prepared high-entropy alloy $Ti_{60}Zr_{20}V_3Nb_{17}$ is mainly composed of a BCC phase. It can be known from a metallograph in Fig. 2 that the prepared high-entropy alloy $Ti_{60}Zr_{20}V_3Nb_{17}$ is of an equiaxed grain structure. It can be known from a test result in Fig. 8 that the prepared high-entropy alloy $Ti_{60}Zr_{20}V_3Nb_{17}$ has the yield strength of 758.06 MPa and the elongation at break of 18.11%. It can be known by test and calculation that the prepared high-entropy alloy $Ti_{60}Zr_{20}V_3Nb_{17}$ has the density of 5.8356 g/cm$^3$.

**Embodiment 2**

**[0019]** A lightweight high-entropy alloy $Ti_{30}Zr_{27}V_{18}Nb_{25}$ with high strength and high plasticity is prepared by the following steps:

step 1, elements Ti, Zr, V and Nb of which the purities are not smaller than 99.7wt% are adopted as raw materials, the raw materials are firstly polished by using a grinding wheel to remove oxide coatings on surfaces of the raw materials, and are then cleaned with anhydrous ethanol by ultrasonic oscillation, and clean raw materials with a total mass of (70$\pm$0.01) g are weighed according to an atomic percentage of Ti:Zr:V:Nb=30:27: 18:25;
step 2, the weighed raw materials are sequentially placed in a water-cooled copper crucible of a high-vacuum non-consumable electric arc smelting furnace according to melting points from low to high, then, vacuumization is performed, and after the vacuum degree in the smelting furnace reaches $2.5\times10^{-3}$ Pa, and argon is filled as a protective gas; before the alloy is smelted, firstly, a pure metal titanium ingot is smelted to further reduce the content of oxygen in a furnace chamber of the smelting furnace, then, alloying smelting is performed, electromagnetic stirring is utilized for alloy homogenization during smelting, and an alloy liquid generated by smelting is cooled to obtain an alloy ingot; and the alloy ingot is overturned and is repeatedly smelted for four times to obtain a high-entropy alloy ingot; and
step 3, the high-entropy alloy ingot is sealed in an argon-filled quartz tube to be subjected to solution treatment at the temperature of 1200°C, and the temperature is kept for 1 h to obtain the high-entropy alloy $Ti_{30}Zr_{27}V_{18}Nb_{25}$.

**[0020]** It can be known from the XRD spectrum in Fig. 1 that the prepared high-entropy alloy $Ti_{30}Zr_{27}V_{18}Nb_{25}$ is mainly composed of a BCC phase. It can be Known from a metallograph in Fig. 3 that the prepared high-entropy alloy $Ti_{30}Zr_{27}V_{18}Nb_{25}$ is of an equiaxed grain structure. It can be known from a test result in Fig. 8 that the prepared high-entropy alloy $Ti_{30}Zr_{27}V_{18}Nb_{25}$ has the yield strength of 991.64 MPa and the elongation at break of 12.95%. It can be known by test and calculation that the prepared high-entropy alloy $Ti_{30}Zr_{27}V_{18}Nb_{25}$ has the density of 6.0938 g/cm$^3$.

**Embodiment 3**

**[0021]** A lightweight high-entropy alloy $Ti_{50}Zr_{18}V_{12}Nb_{16}Al_4$ with high strength and high plasticity is prepared by the following steps:

step 1, elements Ti, Zr, V, Nb and Al of which the purities are not smaller than 99.7wt% are adopted as raw materials, the raw materials are firstly polished by using a grinding wheel to remove oxide coatings on surfaces of the raw materials, and are then cleaned with anhydrous ethanol by ultrasonic oscillation, and clean raw materials with a total mass of (70$\pm$0.01) g are weighed according to an atomic percentage of Ti:Zr:V:Nb:Al=50:18:12:16:4;
step 2, the weighed raw materials are sequentially placed in a water-cooled copper crucible of a high-vacuum non-consumable electric arc smelting furnace according to melting points from low to high, then, vacuumization is performed, and after the vacuum degree in the smelting furnace reaches $2.5\times10^{-3}$ Pa, and argon is filled as a protective gas; before the alloy is smelted, firstly, a pure metal titanium ingot is smelted to further reduce the content of oxygen in a furnace chamber of the smelting furnace, then, alloying smelting is performed, electromagnetic stirring is utilized for alloy homogenization during smelting, and an alloy liquid generated by smelting is cooled to obtain an alloy ingot; and the alloy ingot is overturned and is repeatedly smelted for four times to obtain a high-entropy alloy ingot; and
step 3, the high-entropy alloy ingot is sealed in an argon-filled quartz tube to be subjected to solution treatment at the temperature of 1000°C, and the temperature is kept for 3 h to obtain the high-entropy alloy $Ti_{50}Zr_{18}V_{12}Nb_{16}Al_4$.

**[0022]** It can be known from the XRD spectrum in Fig. 1 that the prepared high-entropy alloy $Ti_{50}Zr_{18}V_{12}Nb_{16}Al_4$ is mainly composed of a BCC phase. It can be known from a metallograph in Fig. 4 that the prepared high-entropy alloy $Ti_{50}Zr_{18}V_{12}Nb_{16}Al_4$ is of an equiaxed grain structure. It can be known from a test result in Fig. 8 that the prepared high-entropy alloy $Ti_{50}Zr_{18}V_{12}Nb_{16}Al_4$ has the yield strength of 795.2 MPa and the elongation at break of 36.57%. It can be known by test and calculation that the prepared high-entropy alloy $Ti_{50}Zr_{18}V_{12}Nb_{16}Al_4$ has the density of 5.6072 g/cm$^3$.

**Embodiment 4**

**[0023]** A lightweight high-entropy alloy

$Ti_{40}Zr_{23}V_{13}Nb_{19}Al_5$ with high strength and high plasticity is prepared by the following steps:

step 1, elements Ti, Zr, V, Nb and Al of which the purities are not smaller than 99.7wt% are adopted as raw materials, the raw materials are firstly polished by using a grinding wheel to remove oxide coatings on surfaces of the raw materials, and are then cleaned with anhydrous ethanol by ultrasonic oscillation, and clean raw materials with a total mass of (70±0.01) g are weighed according to an atomic percentage of Ti:Zr:V:Nb:Al=40:23:13:19:5;
step 2, the weighed raw materials are sequentially placed in a water-cooled copper crucible of a high-vacuum non-consumable electric arc smelting furnace according to melting points from low to high, then, vacuumization is performed, and after the vacuum degree in the smelting furnace reaches $2.5\times10^{-3}$ Pa, and argon is filled as a protective gas; before the alloy is smelted, firstly, a pure metal titanium ingot is smelted to further reduce the content of oxygen in a furnace chamber of the smelting furnace, then, alloying smelting is performed, electromagnetic stirring is utilized for alloy homogenization during smelting, and an alloy liquid generated by smelting is cooled to obtain an alloy ingot; and the alloy ingot is overturned and is repeatedly smelted for four times to obtain a high-entropy alloy ingot; and
step 3, the high-entropy alloy ingot is sealed in an argon-filled quartz tube to be subjected to solution treatment at the temperature of 1100°C, and the temperature is kept for 3 h to obtain the high-entropy alloy $Ti_{40}Zr_{23}V_{13}Nb_{19}Al_5$.

**[0024]** It can be known from the XRD spectrum in Fig. 1 that the prepared high-entropy alloy $Ti_{40}Zr_{23}V_{13}Nb_{19}Al_5$ is mainly composed of a BCC phase. It can be known from a metallograph in Fig. 5 that the prepared high-entropy alloy $Ti_{40}Zr_{23}V_{13}Nb_{19}Al_5$ is of an equiaxed grain structure. It can be known from a test result in Fig. 8 that the prepared high-entropy alloy $Ti_{40}Zr_{23}V_{13}Nb_{19}Al_5$ has the yield strength of 1077.3 MPa and the elongation at break of 25.84%. It can be known by test and calculation that the prepared high-entropy alloy $Ti_{40}Zr_{23}Vi_3Nbi_9Al_5$ has the density of 5.9201 g/cm$^3$.

**Embodiment 5**

**[0025]** A lightweight high-entropy alloy $Ti_{30}Zr_{45}Nb_7Al_8Hf_{10}$ with high strength and high plasticity is prepared by the following steps:

step 1, elements Ti, Zr, Nb, Al and Hf of which the purities are not smaller than 99.7wt% are adopted as raw materials, the raw materials are firstly polished by using a grinding wheel to remove oxide coatings on surfaces of the raw materials, and are then cleaned with anhydrous ethanol by ultrasonic oscillation, and clean raw materials with a total mass of (70±0.01) g are weighed according to an atomic percentage of Ti:Zr:Nb:Al:Hf=30:45:7:8:10;
step 2, the weighed raw materials are sequentially placed in a water-cooled copper crucible of a high-vacuum non-consumable electric arc smelting furnace according to melting points from low to high, then, vacuumization is performed, and after the vacuum degree in the smelting furnace reaches $2.5\times10^{-3}$ Pa, and argon is filled as a protective gas; before the alloy is smelted, firstly, a pure metal titanium ingot is smelted to further reduce the content of oxygen in a furnace chamber of the smelting furnace, then, alloying smelting is performed, electromagnetic stirring is utilized for alloy homogenization during smelting, and an alloy liquid generated by smelting is cooled to obtain an alloy ingot; and the alloy ingot is overturned and is repeatedly smelted for four times to obtain a high-entropy alloy ingot; and
step 3, the high-entropy alloy ingot is sealed in an argon-filled quartz tube to be subjected to solution treatment at the temperature of 1200°C, and the temperature is kept for 12 h to obtain the high-entropy alloy $Ti_{30}Zr_{45}Nb_7Al_8Hf_{10}$.

**[0026]** It can be known from the XRD spectrum in Fig. 1 that the prepared high-entropy alloy $Ti_{30}Zr_{45}Nb_7Al_8Hf_{10}$ is mainly composed of a BCC phase. It can be known from a metallograph in Fig. 6 that the prepared high-entropy alloy $Ti_{30}Zr_{45}Nb_7Al_8Hf_{10}$ is of an equiaxed grain structure. It can be known from a test result in Fig. 8 that the prepared high-entropy alloy $Ti_{30}Zr_{45}Nb_7Al_8Hf_{10}$ has the yield strength of 710.59 MPa and the elongation at break of 12.35%. It can be known by test and calculation that the prepared high-entropy alloy $Ti_{30}Zr_{45}Nb_7Al_8Hf_{10}$ has the density of 6.4338 g/cm$^3$.

**Embodiment 6**

**[0027]** A lightweight high-entropy alloy $Ti_{50}Zr_{25}V_7Nb_{12}Al_5Fe_1$ with high strength and high plasticity is prepared by the following steps:

step 1, elements Ti, Zr, V, Nb, Al and Fe of which the purities are not smaller than 99.7wt% are adopted as raw materials, the raw materials are firstly polished by using a grinding wheel to remove oxide coatings on surfaces of the raw materials, and are then cleaned with anhydrous ethanol by ultrasonic oscillation, and clean raw materials with a total mass of (70±0.01) g are weighed according to an atomic percentage of Ti:Zr:V:Nb:Al:Fe=50:25:7:12:5:1;
step 2, the weighed raw materials are sequentially placed in a water-cooled copper crucible of a high-vacuum non-consumable electric arc smelting furnace according to melting points from low to high, then, vacuumization is performed, and after the vacuum degree in the smelting furnace reaches

2.5×10$^{-3}$ Pa, and argon is filled as a protective gas; before the alloy is smelted, firstly, a pure metal titanium ingot is smelted to further reduce the content of oxygen in a furnace chamber of the smelting furnace, then, alloying smelting is performed, electromagnetic stirring is utilized for alloy homogenization during smelting, and an alloy liquid generated by smelting is cooled to obtain an alloy ingot; and the alloy ingot is overturned and is repeatedly smelted for four times to obtain a high-entropy alloy ingot; and step 3, the high-entropy alloy ingot is sealed in an argon-filled quartz tube to be subjected to solution treatment at the temperature of 1000°C, and the temperature is kept for 12 h to obtain the high-entropy alloy $Ti_{50}Zr_{25}V_7Nb_{12}Al_5Fe_1$.

**[0028]** It can be known from the XRD spectrum in Fig. 1 that the prepared high-entropy alloy $Ti_{50}Zr_{25}V_7Nb_{12}Al_5Fe_1$ is mainly composed of a BCC phase. It can be known from a metallograph in Fig. 7 that the prepared high-entropy alloy $Ti_{50}Zr_{25}V_7Nb_{12}Al_5Fe_1$ is of an equiaxed grain structure. It can be known from a test result in Fig. 8 that the prepared high-entropy alloy $Ti_{50}Zr_{25}V_7Nb_{12}Al_5Fe_1$ has the yield strength of 995.49 MPa and the elongation at break of 9.45%. It can be known by test and calculation that the prepared high-entropy alloy $Ti_{50}Zr_{25}V_7Nb_{12}Al_5Fe_1$ has the density of 5.5533 g/cm$^3$.

## Claims

1. A lightweight high-entropy alloy with high strength and high plasticity, **characterized in that** the high-entropy alloy is marked as $Ti_aZr_bV_cNb_dM_x$ according to an atomic number ratio, M is more than one of Al, Hf, Cr, Fe, Mg, Be, Li, Mo, Co, Ni, Si, B, O and N, wherein $25<a\leq65$, $0<b\leq55$, $0\leq c<25$, $0<d\leq35$, $0\leq x<20$, $a+b+c+d+x=100$, and c and x cannot be 0 at the same time.

2. The lightweight high-entropy alloy with high strength and high plasticity according to claim 1, **characterized in that** in $Ti_aZr_bV_cNb_dM_x$, $25<a\leq60$, $15\leq b\leq50$, $0\leq c<25$, $5\leq d\leq30$, $0\leq x<20$, $a+b+c+d+x=100$, and c and x cannot be 0 at the same time.

3. The lightweight high-entropy alloy with high strength and high plasticity according to claim 2, **characterized in that** M is more than one of Al, Hf, Cr, Fe, Mg, Be, Li, Mo, Co and Ni.

4. A preparation method of the lightweight high-entropy alloy with high strength and high plasticity according to any one of claims 1-3, **characterized in that** the method comprises the following steps:

   step 1, placing clean elemental raw materials Ti, Zr, V, Nb and M into a smelting furnace of which the vacuum degree is smaller than or equal to 2.5×10$^{-3}$ Pa, and filling the smelting furnace with a protective gas; then, performing smelting, and cooling an alloy liquid generated by smelting to obtain an alloy ingot; and overturning the alloy ingot, and performing repeated smelting for more than three times to obtain a high-entropy alloy ingot; and
   step 2, sealing the high-entropy alloy ingot in an argon-filled quartz tube, performing solution treatment at the temperature of 900-1200°C, and keeping the temperature for 1-12 h to obtain the high-entropy alloy.

5. The preparation method of the lightweight high-entropy alloy with high strength and high plasticity according to claim 4, **characterized in that** purities of the elemental raw materials Ti, Zr, V, Nb and M are respectively greater than or equal to 99.7wt%.

6. The preparation method of the lightweight high-entropy alloy with high strength and high plasticity according to claim 4, **characterized in that** an electric arc smelting furnace is selected for smelting.

7. The preparation method of the lightweight high-entropy alloy with high strength and high plasticity according to claim 4, **characterized in that** the protective gas is argon.

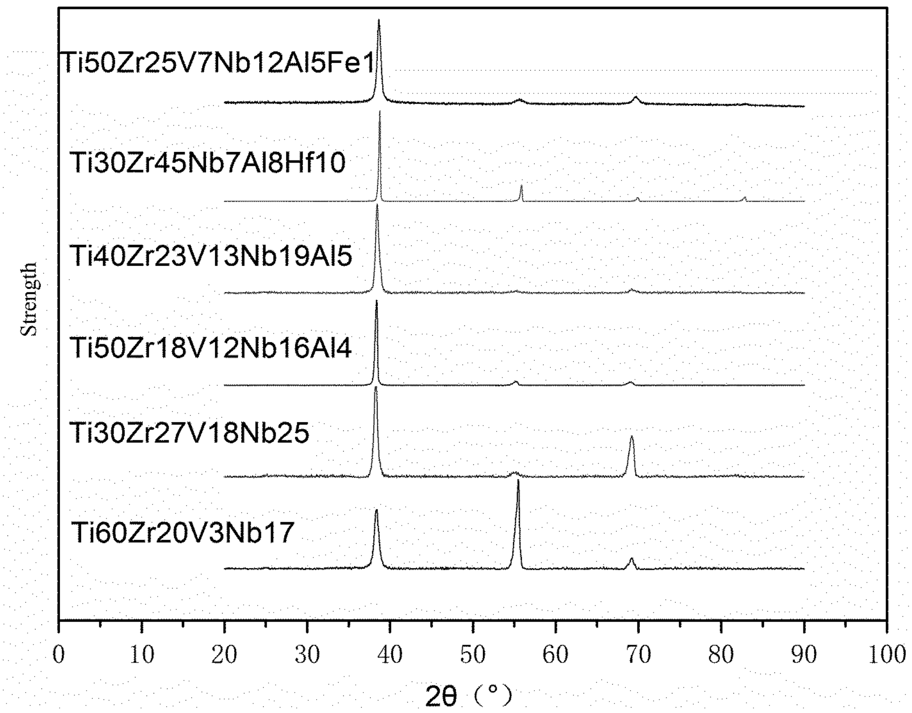
Ti50Zr25V7Nb12Al5Fe1
Ti30Zr45Nb7Al8Hf10
Ti40Zr23V13Nb19Al5
Ti50Zr18V12Nb16Al4
Ti30Zr27V18Nb25
Ti60Zr20V3Nb17
Strength
0
10
20
30
40
50
60
70
80
90
100
2θ（°）

Fig. 1

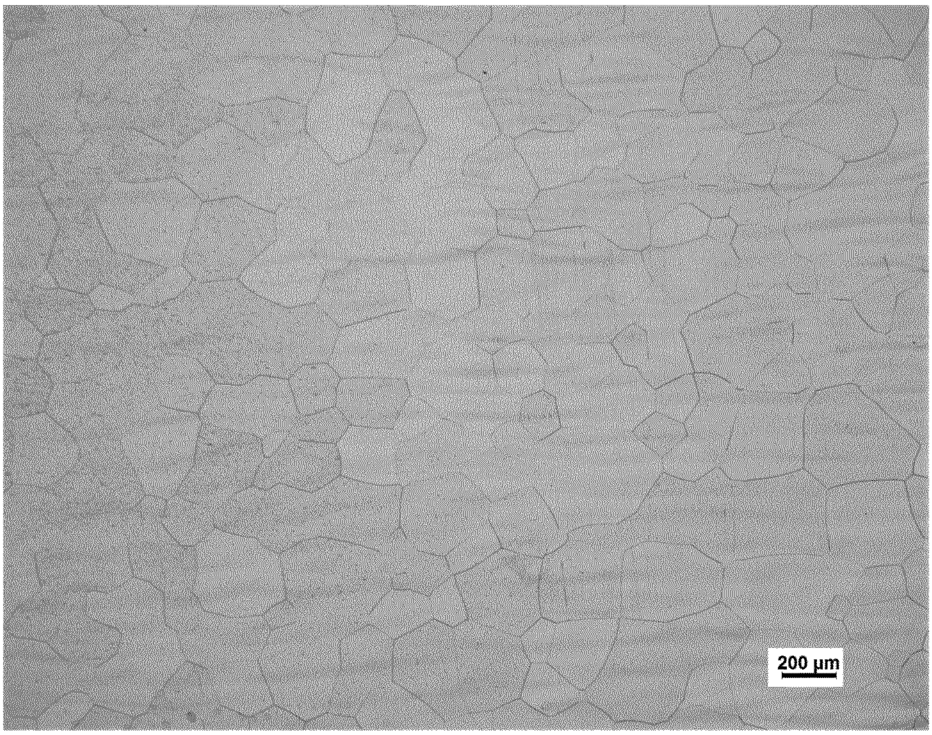
200 μm

Fig. 2

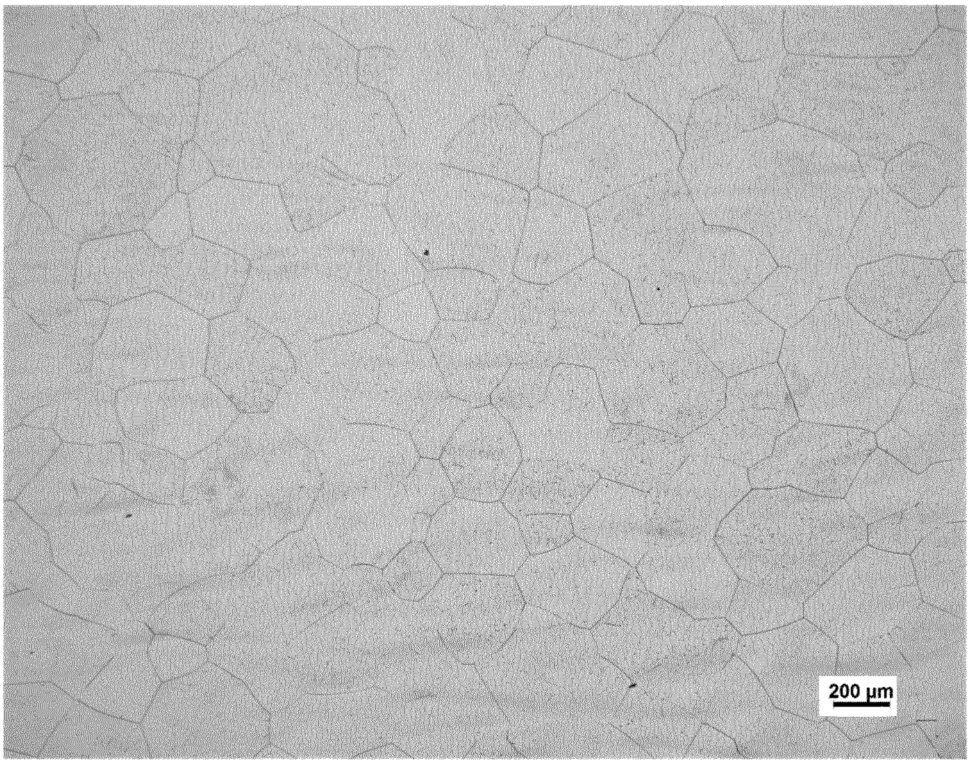


Fig. 3

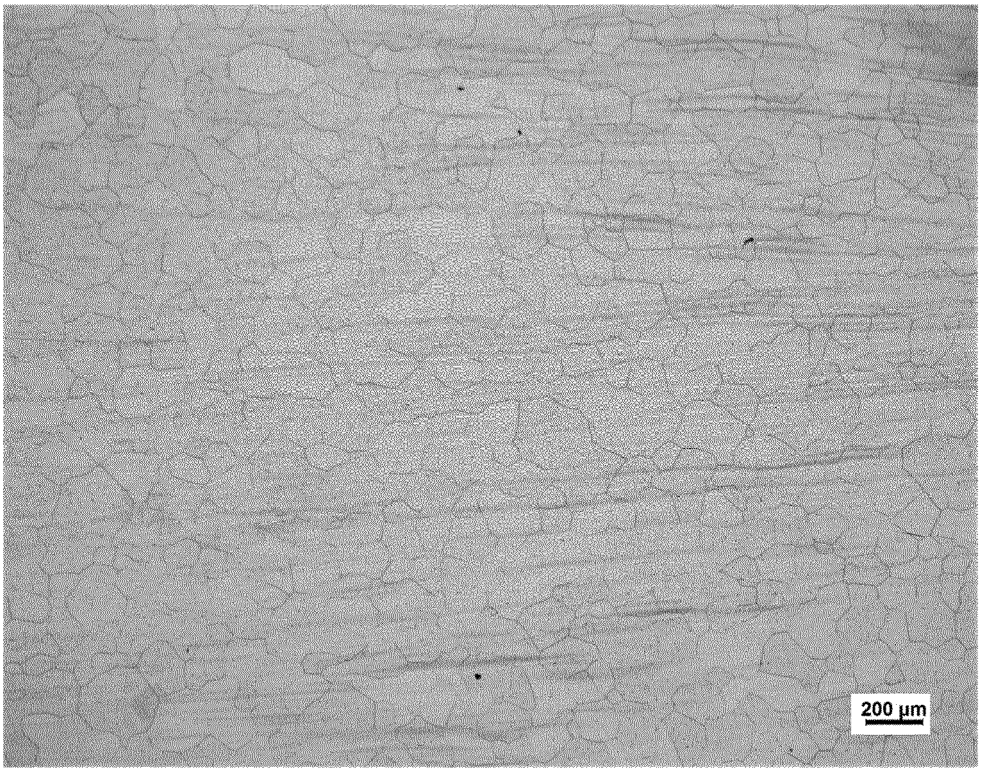


Fig. 4

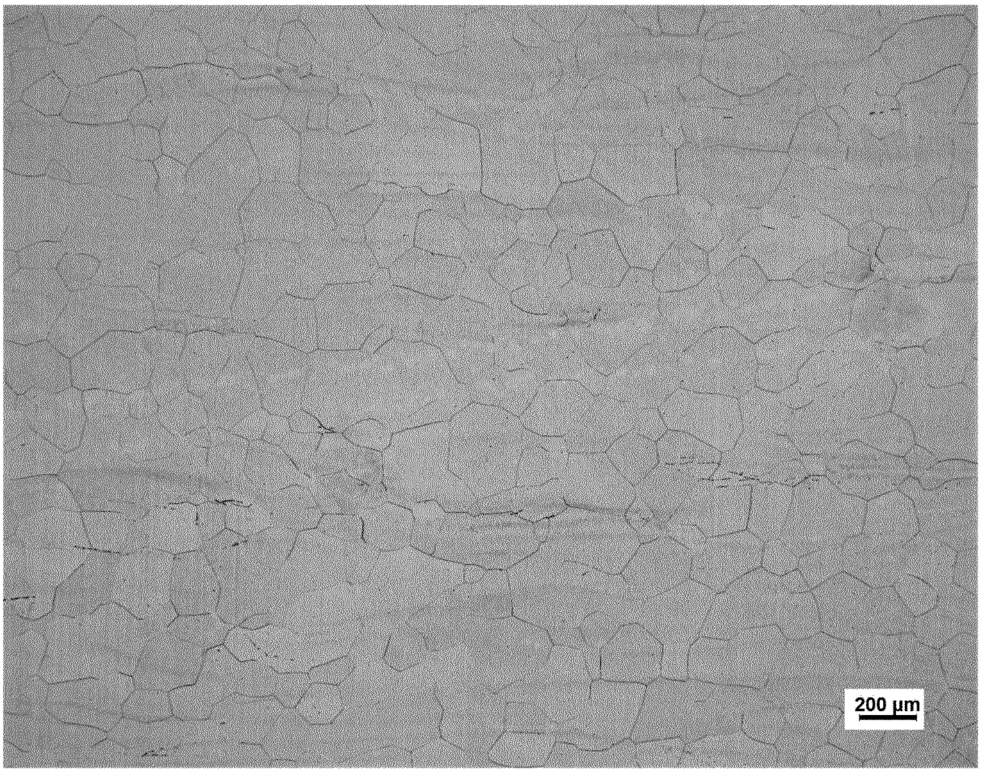


Fig. 5

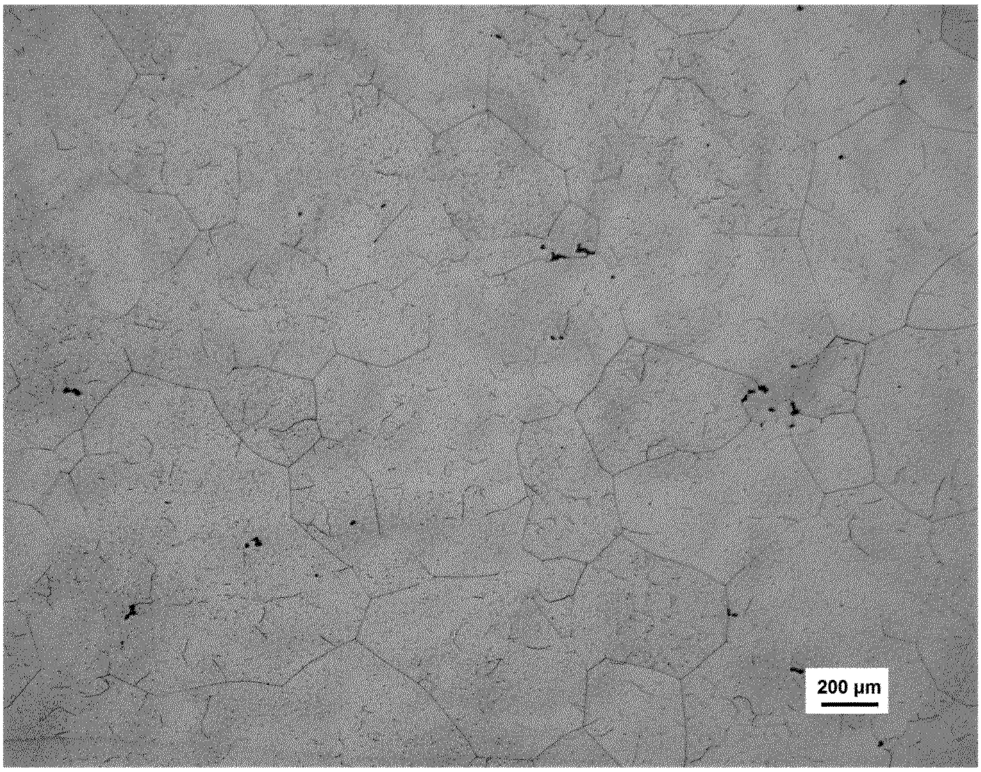


Fig. 6

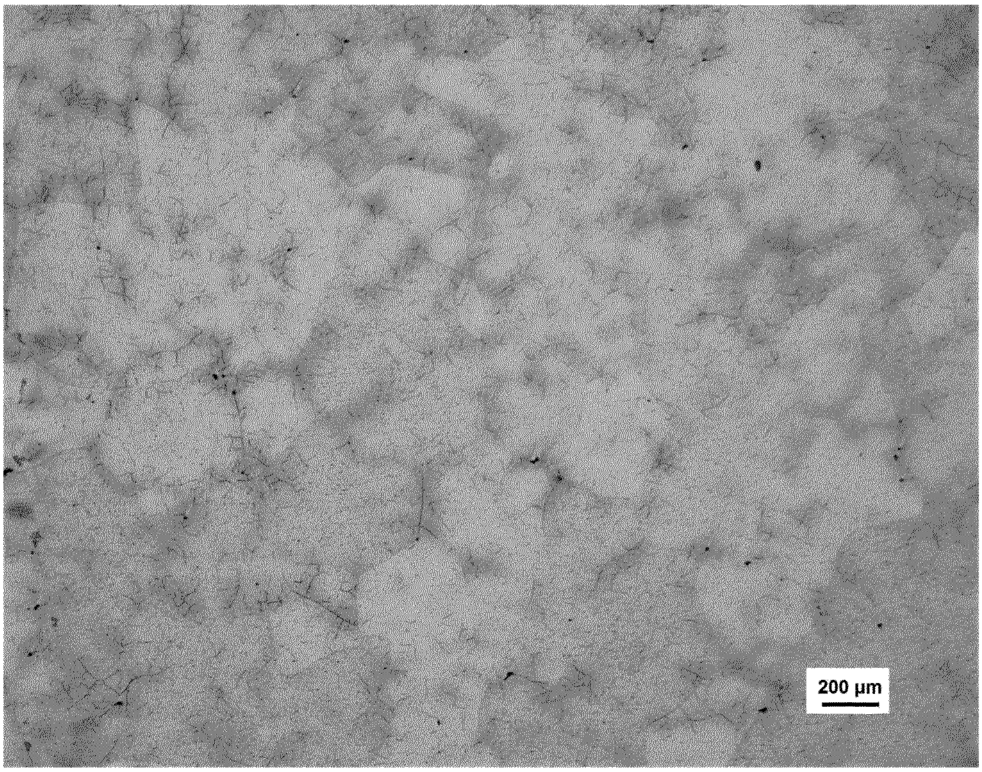
200 µm

Fig. 7

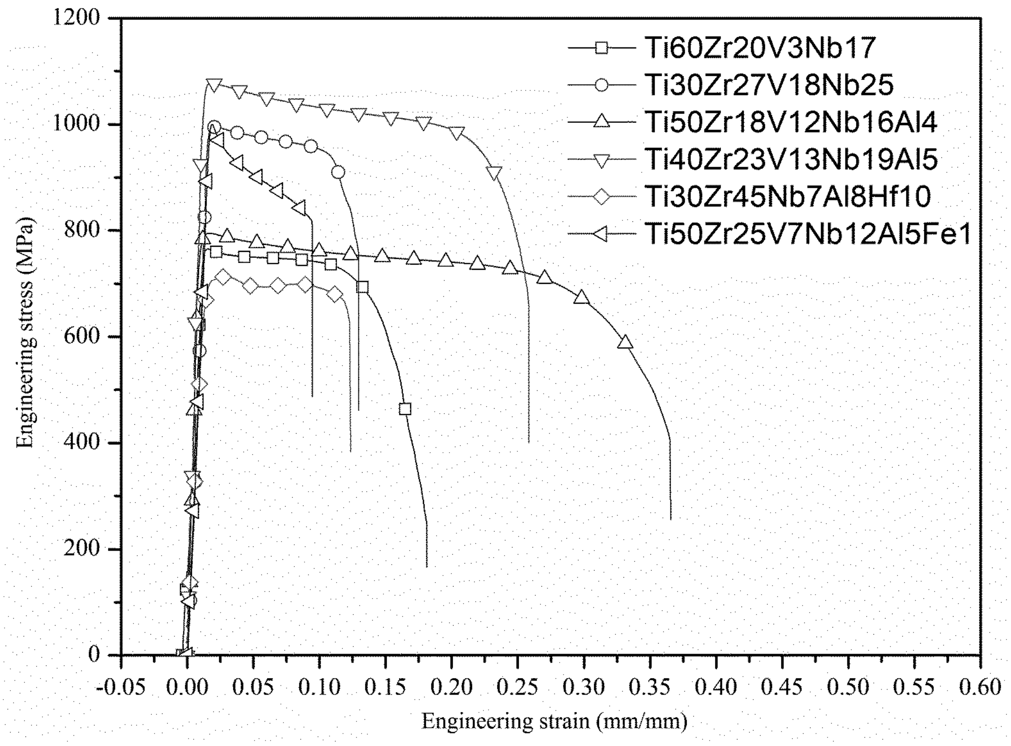
Ti60Zr20V3Nb17
Ti30Zr27V18Nb25
Ti50Zr18V12Nb16Al4
Ti40Zr23V13Nb19Al5
Ti30Zr45Nb7Al8Hf10
Ti50Zr25V7Nb12Al5Fe1
Engineering stress (MPa)
Engineering strain (mm/mm)
0
200
400
600
800
1000
1200
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60

Fig. 8

**INTERNATIONAL SEARCH REPORT**

International application No.
**PCT/CN2019/000222**

**A. CLASSIFICATION OF SUBJECT MATTER**

C22C 30/00(2006.01)i；C22C 1/02(2006.01)i；C22F 1/00(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,C22F

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

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

CNABS, CNTXT, DWPI, SIPOABS, 中国期刊网全文数据库, CHINA JOURNAL FULL-TEXT DATABASE: 北京理工大学, 薛云飞, 陈松岫, 王亮, 曹堂清, 王本鹏, 王富耻, 王鲁, 高熵, 强度, 塑性, 密度, Ti, Nb, Zr, V, Al, Hf, Cr, Fe, Mg, Be, Li, Mo, Co, Ni, Si, B, O, N, HIGH ENTROPY, STRENGTH, PLASTICIT+, DUCTILT+, DENSITY

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| PX | CN 109402482 A (BEIJING INSTITUTE OF TECHNOLOGY) 01 March 2019 (2019-03-01) claims 1-7 | 1-7 |
| X | CN 107419154 A (UNIVERSITY OF SCIENCE AND TECHNOLOGY BEIJING) 01 December 2017 (2017-12-01) description, paragraphs [0008], [0024] and [0031]-[0041], and table 1 | 1-7 |
| X | CN 108220742 A (BEIJING INSTITUTE OF TECHNOLOGY) 29 June 2018 (2018-06-29) claim 1 | 1-7 |
| X | CN 107142410 A (XIANGTAN UNIVERSITY) 08 September 2017 (2017-09-08) claim 1 | 1-7 |
| X | CN 108220740 A (XIANGTAN UNIVERSITY) 29 June 2018 (2018-06-29) claim 1 | 1-7 |
| X | CN 103602874 A (UNIVERSITY OF SCIENCE AND TECHNOLOGY BEIJING) 26 February 2014 (2014-02-26) claim 1 | 1-7 |

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

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| **10 January 2020** | **21 January 2020** |

| Name and mailing address of the ISA/CN | Authorized officer |
|---|---|
| **China National Intellectual Property Administration**<br>**No. 6, Xitucheng Road, Jimenqiao Haidian District, Beijing 100088**<br>**China** | |
| Facsimile No. **(86-10)62019451** | Telephone No. |

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**INTERNATIONAL SEARCH REPORT**

International application No.
**PCT/CN2019/000222**

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | CN 103602872 A (UNIVERSITY OF SCIENCE AND TECHNOLOGY BEIJING) 26 February 2014 (2014-02-26)<br>claim 1 | 1-7 |
| X | CN 104213013 A (HARBIN INSTITUTE OF TECHNOLOGY) 17 December 2014 (2014-12-17)<br>claim 1 | 1-7 |
| A | CN 103710607 A (UNIVERSITY OF SCIENCE AND TECHNOLOGY BEIJING) 09 April 2014 (2014-04-09)<br>claim 1 | 1-7 |
| A | US 2017314097 A1 (KOREA ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY et al.) 02 November 2017 (2017-11-02)<br>entire document | 1-7 |

Form PCT/ISA/210 (second sheet) (January 2015)

**INTERNATIONAL SEARCH REPORT**
**Information on patent family members**

International application No.
**PCT/CN2019/000222**

| Patent document cited in search report | Publication date (day/month/year) | Patent family member(s) | Publication date (day/month/year) |
|---|---|---|---|
| CN 109402482 A | 01 March 2019 | None | |
| CN 107419154 A | 01 December 2017 | CN 107419154 B | 15 February 2019 |
| CN 108220742 A | 29 June 2018 | None | |
| CN 107142410 A | 08 September 2017 | CN 107142410 B | 24 August 2018 |
| CN 108220740 A | 29 June 2018 | None | |
| CN 103602874 A | 26 February 2014 | CN 103602874 B | 02 March 2016 |
| CN 103602872 A | 26 February 2014 | CN 103602872 B | 23 September 2015 |
| CN 104213013 A | 17 December 2014 | CN 104213013 B | 21 September 2016 |
| CN 103710607 A | 09 April 2014 | CN 103710607 B | 06 January 2016 |
| US 2017314097 A1 | 02 November 2017 | KR 20170124441 A | 10 November 2017 |
| | | KR 101927611 B1 | 10 December 2018 |

Form PCT/ISA/210 (patent family annex) (January 2015)