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(71) Applicant: **Advanced Alloys S.A.**
1201 Genève (CH)

(72) Inventor: **Advanced Alloys S.A.**
1201 Genève (CH)

(74) Representative: **Einsel, Martin**
Patentanwälte
Einsel & Kollegen
Jasperallee 1A
38102 Braunschweig (DE)

(54) **METHOD FOR PRODUCING COMPOSITE METAL MATERIALS BY CRYSTALLISATION IN A CENTRIFUGE FORCE FIELD**

(57) The invention relates to metallurgy. The inventive method involves casting low-heated molten metals or alloys into the lined centrifuge crystalliser in a specified order and volumes and in the shortest time in such a way that a gradient smelt is formed along a casting-form radius. The thermodynamic characteristics of the crystalliser together with the superheat value of casted melts, when the greatest volume uniform cooling rate of the gra-

dient melt is equal to or less than 0.5 DEG C/sec, provide the life time thereof which is sufficient for forming the gradient melt, carrying out diffusion processes therein and for organising a crystallisation front extending from the external ring-shaped part of the casting-form towards the center thereof, prior to the generation of natural crystallisation processes.

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Description

FIELD OF THE INVENTION

5 **[0001]** The invention relates to metallurgy, specifically to processes for producing new metal materials of varied nature, in particular, to the production of composite metal materials.

BACKGROUND OF THE INVENTION

10 **[0002]** Bimetals are the simplest composite metal materials that are most widely used in industry. There are many multilayered metal materials used for different purposes. A layer of protective materials is frequently applied to a basic material in a process termed plating.

[0003] The growing demand for such materials is met in part today by cold welding of the components during rolling, hot forging, or pressing. Some of the welding techniques known today use the energy of explosion, and a variety of other processes. In a majority of situations, cold welding of solid components does not produce the desired depth of diffusion at the weld boundary, and sometimes no diffusion occurs at all. Fusion welding can only be used to join components for a limited number of metals and alloys to produce items of simple configuration. Still, strength is reduced in areas where diffusion does not extend deep enough into the weld zone, specific corrosion is accelerated at the joint of the components, the joint shows signs of aging, and other defects affecting the service properties of composite metal materials develop.

[0004] A prior art method for continuously casting bimetallic ingots, for example, comprising feeding different materials and a steel strip to prevent intermixing thereof into a crystallizer in an apparatus for performing the method (Japanese Application No. 55-68156, 1980).

25 **[0005]** The prior art method and apparatus are disadvantageous because a complicated and long process is required to prepare the steel strip by dressing, degreasing, clean washing, and so on, all of which complicates the casting process but does not guarantee the required quality of welded metals.

[0006] A prior art method for continuously casting bimetallic billets of small cross-sectional area comprising feeding molten metals at a controlled rate into a crystallizer having movable walls, forming both ingots in a two-phase state, measuring the temperature of the melts, and moving the ingot sides to be welded into contact, and an apparatus comprising a crystallizer having movable walls, a partition, and a temperature sensor (Patent SU No. 539,668, B22D11/00, 1977) are closest to the present invention.

[0007] The prior art method is disadvantageous because the solidifying metals may intermix completely and oxide films may form on the open surfaces of the metal menisci.

35 **[0008]** It is common knowledge that the quality of welding and cohesion of different metals used to cast bimetallic billets depend on the development and characteristics of the two-phase zone of the ingots welded. If the ingots are joined in a liquid or two-phase state, when the share of the solid phase f_s is less than the range between 20% and 40% ($f_s = f_s^* \approx 0.2-0.4$) over the full cross-sectional area of the ingots being joined, the melts are intermixed intensively and, as a result, the mixed composition zone extends as far as the peripheral layers, and the mechanical properties of the bimetallic product deteriorate. For the metals to be joined at a high quality, the two-phase states are first to be achieved in both ingots, and the sides to be joined are then brought into contact, for example, from the outpouring boundary of the alloy having a higher liquidus temperature.

40 **[0009]** Another prior art method for continuously casting bimetallic billets of a small cross-sectional area, comprising feeding melts at a controlled rate into a crystallizer having movable walls, forming two-phase state of both ingots therein, measuring the temperatures of the melts, and moving the ingot sides to be welded into contact, wherein, with the purpose of improving the quality of the products, the ingot sides to be welded are moved into contact at the outpouring boundary of the melt having a higher crystallization temperature (Patent RU No. 2,073,585, B22D11/00, published February 20, 1997). This method is immediate prior art of the present invention.

SUMMARY OF THE INVENTION

50 **[0010]** It is an object of the present invention to produce a desired layered composition of metal materials in liquid phase and to alter the crystallization conditions of the melt by forming a crystallized structure of the composite materials in the centrifuge fields of force.

[0011] The technical result achieved through the use of this invention consists in obtaining multilayered castings of increased strength and structural uniformity leading to a significant (up to 25-30%) improvement in their service properties.

55 **[0012]** The above technical result is attained by a method for producing composite metal materials by crystallization in the field of force of a centrifuge, wherein the low-heated melts of metals or alloys differing in chemical composition are poured one over the other from different smelting zones in a specified sequence and in specified volumes into a

rotating lined centrifuge crystallizer having thermodynamic characteristics of the crystallizer that cause the melt to cool uniformly in volume at a rate that is not higher than 0.5° per second, the centrifuge rotor is rotated at revolutions sufficient to produce a gravity coefficient within the range of 20 to 300, and the melts poured in are maintained superheated for as long as they are in the liquid phase for diffusion processes to develop and directed crystallization to continue until natural crystallization processes begin, the centrifuge being rotated until the cooling casting reaches a temperature at which the natural crystallization processes of the melts used are completed, and after the cooling casting has reached the temperature at which the natural crystallization processes are completed centrifuging is discontinued to allow further cooling of the casting.

[0013] The above characteristics are essential and interrelated to produce a stable combination of essential features sufficient for achieving the desired technical result.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

FIG. 1 is a diagrammatic view of a potential relief around any one atom of the melt before it is exposed to an external field of force;

FIG. 2 is a diagrammatic view showing absence of diffusion PQ before exposure to an external field of force; and

FIG. 3 is a diagrammatic side view of a potential relief around an atom at any point of the melt exposed to an external field of force.

DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

[0015] The present invention helps in a significant degree to eliminate the typical defects of composite metal materials. The invention related to a method for producing layered metal materials by crystallization in the field of force of a centrifuge, wherein low-heated melts of metals or alloys having different chemical compositions are poured from different melting zones in a specified sequence and in specified volumes into a rotating lined centrifuge crystallizer having thermodynamic characteristics allowing the melt to be cooled uniformly at a rate not exceeding 0.5°K/sec, the centrifuge rotor rotates to produce a gravity coefficient of 20 to 300, and the melts poured in are maintained superheated for as long as they are in the liquid phase for diffusion processes to occur and directed crystallization to be completed before the commencement of natural crystallization processes, the centrifuge continuing to rotate until the cooling casting has a temperature at which natural crystallization processes of the melts used have been completed, and when the cooling casting reaches a temperature at which natural crystallization processes have been completed, centrifuging is discontinued for the casting to cool further.

[0016] The present invention is based on a method for producing composite metal materials, said method comprising melting selected metal materials of different chemical and physical compositions in separate melting zones, followed by pouring the low-heated melts in specified volumes and in a specified sequence into a lined casting form of a rotating centrifuge rotor. Simultaneously, the melt is cooled in volume at a rate not exceeding 5°K/sec. In order to produce a desired structure in the casting and obtain solid solutions at the boundaries between the zones of the casting layers, the melt is crystallized in the centrifuge field of force at a gravity coefficient within the range of 20 to 500 (at specified revolutions of the centrifuge rotor) for a time interval equal to the ratio:

$$T = m/aKg,$$

wherein:

a is a coefficient found for each metal-metal pair, depending on the thermodynamic characteristics of the crystallizer and the rate of the crystallization processes;

Kg is the gravity coefficient; and

m is the relative mass of the metals involved in the mutual diffusion process.

[0017] The present invention is based on forced diffusion processes occurring at the stage when a crystalline structure is produced in the melts in fields of force.

[0018] Where a transitional zone is to be provided between the layers in the form of a solid solution, a required level of solubility of element A in element B is to be achieved. The number of atoms n migrating from the melt in a time unit and in a volume unit to the crystalline lattice at an initial concentrations of A is equal to:

$$n = n_s P F \exp \left[-\frac{\bar{U}_A + \Delta A_1}{K T} \right] \quad (1)$$

wherein:

n_s is the number of atoms of metal A in the zone in question;

P is the probability of an atom jump;

F is the oscillation frequency of the atom about its equilibrium position;

$\bar{U}_A$ is the average activation energy of an atom B jumping to the crystalline lattice point of the same element from the melt;

ΔA_1 is additional activation energy required for a similar jump of an atom A (caused by the difference between atoms A and atoms B).

[0019] In the absence of external fields of force, the potential relief in the environment of any melt atom is symmetrical (FIG. 1) resulting in no diffusion occurring through PQ (FIG. 2). Absence of concentration equality is the only possible reason why atoms migrate from medium 2 to medium 1 in this case.

[0020] An external field of force F present with a potential energy E, causes distortion of the initial potential barrier (FIG. 3). The heights of the potential barriers to a possible jump of an atom A in either direction are equal, respectively, to:

$$\begin{aligned} U_1 &= \bar{U}_A - F \delta / 2 + \Delta A_1 \\ U_2 &= \bar{U}_A + F \delta / 2 + \Delta A_1 \end{aligned} \quad (2)$$

wherein:

δ is the order of the crystalline lattice.

[0021] The general asymmetry of the potential relief is equal to:

$$\Delta U = F \delta \quad (3)$$

[0022] The presence of U produces an asymmetric flux of atoms n_2 that can be found from the formula:

$$n_2 = S \bar{V} C_1 \quad (4)$$

wherein:

$\bar{V}$ is the average speed of atoms of type A;

S is the area of the solid phase; and

C_1 is the concentration of atoms of metal A.

[0023] Intermediate calculations disregarded, the final formula describing the total flux n_D of atoms A and B having activation energies from U_a and $U_a + A_1$ is:

$$n_D = \frac{1}{6T^0} \left[\frac{SC_i F \delta}{K T} P_i - n_s \right] \exp \left[\frac{\bar{U}_A + \Delta A_i}{K T} \right] \quad (5)$$

[0024] The difference between the n fluxes depends on the total activation energy ($U_a + A_i$) that may be assumed to be equal to the activation energy at crystallization or melting. It follows, therefore, that with atoms of types A and B present in the melt and having respective sizes and activation energies at solidification, crystallization in the centrifuge field of force results in a solid substitution solution. The solid solution will have, with a probability P , 50% of element A if $A=0$, because the force F is indifferent to atom type. Where the concentration of A in the melt is larger than 0.5 at $A=0$, a solid phase with a prevalence of atoms of type A is produced under these circumstances.

[0025] If atoms A are significantly larger (by 15% to 20%) in size than atoms B, a solid substitution solution cannot be stable, and solid intrusion solutions are produced instead.

[0026] The picture changes significantly if the concentration of larger atoms A exceeds 0.5, in which case the melt of atoms A turns into a solvent for atoms B. Then, atoms B are inserted into the points of the crystalline lattice of atoms A, and a solid substitution solution is produced. All these factors create condition for the production of layered metal materials that are metal composites having a specified chemical gradient.

[0027] The idea of the method is producing composite metal materials at the existing liquid phase in which the diffusion process is accelerated during gradient melt crystallization by directed crystallization of the centrifuge field of force of a specified intensity (specified gravity coefficient). The gravity coefficient value required for obtaining a desired grain size in a specified section of a casting is derived, depending on the grain size, from the gravity coefficient calculated for each metal and alloy. The thermodynamic characteristics of a ring-shaped casting form are to contribute to uniform cooling of a multilayered melt volume at a rate not exceeding $0.5^\circ/\text{sec}$. In this case, a specified melt gradient is achieved by consecutive pouring of desired low-heated melts of required metals or alloys in a specified sequence and in specified volumes. The superheating degree of the melts poured into a preheated ring-shaped casting form of the centrifuge rotor is to maintain a lifetime of the liquid melt phase sufficient for producing a desired gradient melt in the rotating casting form and a directed crystallization process in which the crystallization front moves away from the outer side of the ring-shaped casting form toward the center thereof until natural melt crystallization sets in. After the solidified casting has reached a temperature at which crystallization processes for the particular metals and alloys have been completed, further cooling may proceed at any rate.

[0028] The apparatus for performing the claimed method is a machine having a vertical shaft carrying a rotatable rotor provided with a casting form secured thereon. The rotor is turned by an electric motor at a controlled rotation speed. The desired rotation speed of the centrifuge motor is stabilized by an electronic system. The required thermodynamic characteristics (cooling rate not exceeding $0.5^\circ/\text{sec}$) of the crystallizer casting form are maintained by the casting form lining design and preheating of the internal surface of the casting form before the melt is poured in by gas burner flame to between 200°C and 250°C . The rotor body is made from structural steel 5 mm thick and comprises a fixed bottom part and a detachable top lid. The inner surface of the fixed part has a lining 25 mm thick that is a mixture of fireclay bits, refractory clay, and graphite in a proportion of 7/3/2 to give the required thermodynamic characteristics to the casting form, and 5 mm of graphite to protect the lining against thermal shock as it is filled with the melt.

[0029] The gravity coefficient (revolutions of the centrifuge rotor) may be controlled within the range of 10 to 500 for effecting the following processes:

- (a) producing a gradient melt in the casting form;
- (b) accelerating diffusion between the layers (mutual dissolution) of melts at the boundary of the layers; and
- (c) causing crystallization to be effected from the outer boundary of the ring-shaped casting form toward the center thereof.

[0030] The magnitude of the gravity coefficient at the stage of gradient melt production in the casting form of the centrifuge crystallizer causes the melts poured in to be distributed uniformly along the casting form radius.

[0031] The magnitude of the gravity coefficient at the diffusion stage creates optimal conditions for mutual intermixing and dissolution of the layers at the line of contact thereof.

[0032] The magnitude of the gravity coefficient at the stage of directed crystallization and the volume of the gradient melt formed in the casting form are chosen for the casting to develop a specified structure along the casting form radius.

[0033] The magnitude of the gravity coefficient for the casting process as a whole is selected, together with the volume of the gradient melt formed, in the casting form of the centrifuge crystallizer and promotes diffusion between the layers and formation of the desired structural gradient along the casting form radius.

[0034] The centrifuge rotor is turned until the cooling casting has reached a temperature at which natural crystallization processes of the melt have been completed.

[0035] As the cooling casting reaches a temperature at which natural crystallization processes are completed, centrifuging is discontinued and the casting may be cooled at any rate thereafter.

[0036] Test castings were produced to effect two-sided plating of a test aluminum-magnesium alloy A10Mg containing 10% of magnesium with pure aluminum A99 at the liquid phase of a gradient melt, followed by hot and cold rolling of the castings to a thickness of 2.5 mm. The rotor was turned at 1,700 r.p.m. to produce a gravity coefficient of 220. In addition to the basic melt of alloy A10Mg heated to 850°C, a melt of aluminum A99 heated to 1,000°C was prepared in an auxiliary furnace. A gas burner preheated the centrifuge casting form to 200°C. After the centrifuge rotor has reached the desired r.p.m., the melt of A99 was poured in a layer 5 mm thick, followed by the A10Mg melt poured in a layer having a thickness of 10 mm, and then the A99 melt was poured in a layer 5 mm thick. After 20 minutes of rotor turning with the melt (the time was established experimentally to be enough for the temperature of the solidified casting to drop below 400°C), the crystallizer was stopped and the casting removed. After the casting cooled completely, it was machined in a lathe and the billet was cut up into four equal segments before rolling. The quality of diffusion between the layers was then checked for incomplete diffusion at the joints, and the segments were rolled in the following sequence: hot rolling to a thickness of 6 mm and cold rolling to a thickness of 2.5 mm under a rolling program developed for the A10Mg alloy. The properties of the 2.5 mm thick rolled products were tested. The test results showed a high quality of the gradient casting produced. Test cold rolling was conducted under the same program to a thickness of 1 mm. The rolling of the A10Mg alloy provided with a plating layer on both sides in cold rollers showed a high stabilizing effect of two-sided plating on the rolling process.

INDUSTRIAL APPLICABILITY

[0037] The present invention can be used for producing new metal materials of different nature, in particular, for producing composite metal materials.

Claims

1. A method for producing composite metal materials by crystallization in a centrifuge field of force, wherein low-heated melts of metals or alloys of different chemical composition are poured from separate melting zones one over the other in a specified sequence and in specified volumes into a rotating lined centrifuge crystallizer having thermodynamic characteristics allowing the melt to cool uniformly in volume at a rate not exceeding 0.5°/sec; the centrifuge rotor revolutions are chosen to produce a gravity coefficient within the range of 20 to 300, and the melts poured in remain superheated for as long as they are in a liquid phase for diffusion processes to occur and directed crystallization to be effected before the commencement of natural crystallization processes, the centrifuge being rotated until the cooling casting reaches a temperature at which natural crystallization of the melts used is completed, and centrifuging being discontinued after the cooling casting has reached a temperature at which natural crystallization processes of the melts used are completed for the casting to cool further.

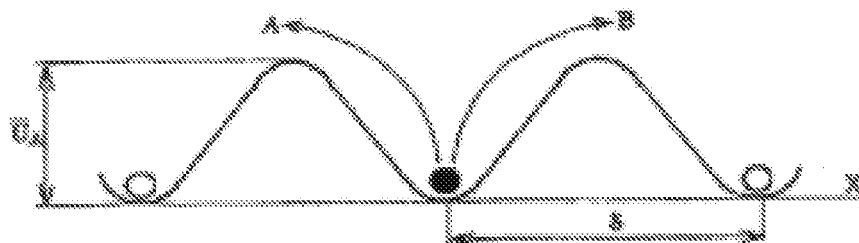


FIG. 1

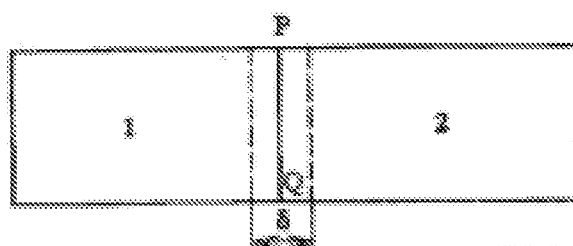


FIG. 2

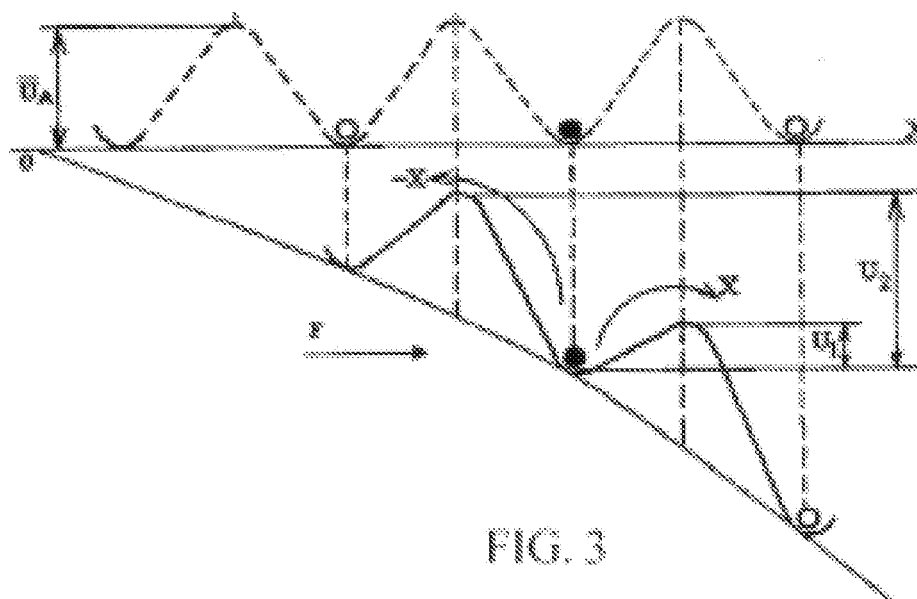


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/RU 2009/000122

A. CLASSIFICATION OF SUBJECT MATTER B22D 13/00 (2006.01) 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) B22D 13/00, 13/02, 19/16 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) ESP@SENET, PAJ, RUPTO, USPTO, WIPO		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SU 789227 A (INSTITUT PROBLEM LITYA AN UKRAINSKOI SSR) 23.12.1980, the whole document	1
Y	WO 1994/002270 A1 (POPOV ANATOLY VLADIMIROVICH et al.) 03.02.1994, p. 3-6, 11, 12, the claims, the figures	1
A	SU 859019 A (NAUCHNO-PROIZVODSTVENNOE OBEDINENIE PO TEKHNologii MASHINOSTROENIYA) 30.08.1981	1
A	SU 1297987 A1 (UKRAINSKY NAUCHNO-ISSLEDOVATELSKY INSTITUT METALLOV) 23.03.1987	1
☐ 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 20 July 2009 (20.07.2009)		Date of mailing of the international search report 20 August 2009 (20.08.2009)
Name and mailing address of the ISA/ RU		Authorized officer
Facsimile No.		Telephone No.

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 55068156 A [0004]
- SU 539668 [0006]
- RU 2073585 [0009]