A New Way of Manufacturing Bimetal Products on the Basis of the Technology of Casting with Crystallization Under Pressure

Ruslan V. Kuznetsov and Pavel A. Kuznetsov

Abstract The paper presents the analysis of possible combinations of raw materials during manufacturing bimetallic compositions. A variety of materials makes it necessary to apply new combinations of familiar processes of materials processing and search for new ways of bimetals production meeting the needs of different branches of industry. The possibilities of obtaining bimetallic compounds on the basis of casting alloys and powder sintered materials are not sufficiently studied. By means of the analysis, carried out using a morphological matrix, a new method of manufacturing bimetallic products based on the technology of casting with crystallization under pressure was developed. An experimental press mold and an experimental stand were developed to study the main parameters of the proposed process on the samples in the form of bimetallic bushings—models of bimetallic bearings. Casting aluminum alloy AK9ch was used for the base material. The working layers were sintered powder materials made of graphite bronze and iron. The main methods of studying the obtained bimetallic samples were mechanical tests of strength of the layers interconnection and metallographic studies of their interconnection zone. The paper discusses the issues of searching for rational modes of casting with crystallization under the pressure of aluminum alloys together with the working elements made of sintered materials with special properties. The possibility of application of the obtained bimetallic products in sliding friction joints used in general mechanical engineering products is considered. Acoustic emission, radiographic testing, pressure vessels, stainless steel, cracks in the welds, sequence of application of testing methods

Keywords Composite material · Sintered material · Bimetal · Silumin · Iron powder · Bronze powder · Liquid metal stamping · Crystallization · Antifriction material · Galvanizing · Intermetallic compounds

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A. N. Evgrafov (ed.), *Advances in Mechanical Engineering*,
Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-3-030-39500-1_13

1 Introduction

The nomenclature and volumes of bimetallic materials and products made of them are currently increasing intensively. Such innovative development is caused by both the needs of different industrial branches and emergence of new materials with unique properties and technologies of their production [1–4]. By the field of application of bimetallic materials, they are distinguished into corrosion-resistant, antifriction, electrotechnical, instrumental, wear-resistant, thermo-bimetals, bimetals for installation works, and others.

The diversity of bimetallic materials is due to the large number of possible combinations of raw materials [4–6]. The most common combinations can be considered to be “compact-compact”, “plastic-plastic”, “compact-plastic”, “composite-composite”, “composite-plastic” combinations. Application of various technological processes used in manufacture of bimetals, in turn, makes it possible to control the properties necessary to perform specific tasks [5–7]. Almost in all bimetals, one of the materials is a working layer with special properties, the second material is a “matrix”, which performs auxiliary functions, such as supporting ones, i.e. for attaching the working layer. However, such technologies of bimetals production are of considerable interest when the “matrix” serves not only for attaching the working layer, but is a product that performs certain functions [8]. Undoubtedly, from the economic point of view, the options in which the bimetal layers are connected simultaneously with the manufacture of the product itself are of a greater interest. Modern technologies that correspond to these goals are not sufficiently studied and require more thorough research. In particular, the technologies for obtaining bimetals from liquid metal and powder materials have not been sufficiently studied. Application of the powder metallurgy technology makes it possible to obtain a working layer of a bimetallic product with the highest and special physical, mechanical, and operational properties [9–12].

For the analysis of possible combinations of the process of manufacturing a bimetallic product from liquid metal and a sintered material, it is proposed to consider the morphological matrix presented in Table 1.

The proposed matrix considers only options of obtaining bimetallic products on the basis of the technology of casting with crystallization under pressure, as a process that significantly improves the quality of the cast metal. Stamping of a liquid metal is carried out together with working inserts of powder materials with the set properties. During implementation of the process, the following options are possible.

Option 1 implies making a working insert out of powder with the required properties, sintering it, installing it in a mold (matrix), pouring the liquid metal into the mold, and stamping them together to produce a high-quality bimetallic product. In order to achieve the necessary qualities, it is also possible to carry out additional machining and impregnation with lubricants.

Important features of the proposed technology are the possibility to vary the modes of operations in a wide range, as well as the possibility of intensifying the process in individual operations. Option 2 implies applying a special material (e.g. zinc) to

Table 1 Morphological matrix of comparison of technological options of production of composite layered bushings from liquid metal and sintered powders

No.	Technological operations	Production options			
		I	II	III	IV
1	Preparation of a powder material for the working layer	O	O	O	O
2	Pressing of the working insert	O	O	O	O
3	Sintering of the working insert	O	O	O	O
4	Application of an adhesive activating material to the insert		O		O
5	Installation of the working insert into the mold	O	O		
6	Pouring a liquid metal base into the mold	O	O	O	O
7	Insertion of the working insert into the liquid metal			O	O
8	Joint stamping of the liquid metal and the working insert	O	O	O	O
9	Heat treatment of the stamped Bimetallic product				O
10	Layered product calibration				O
11	Machining	O	O	O	O
12	Thermochemical treatment		O		O
13	Impregnation with lubricants	O		O	
14	Control	O	O	O	O

the sintered working insert, which activates the process of forming a strong bond between the layers during stamping. Installing the insert into the mold is done before pouring a liquid metal.

The working insert can be inserted into the already poured liquid metal, fixed in the desired position, and then the joint stamping of the liquid metal and the sintered insert can be carried out, which is reflected in options 3 and 4, different from each other by auxiliary operations of heat treatment, impregnation, etc. For example, the finishing shaping of the working surface, such as calibration, can effectively adjust the pore size (option 4).

Based on the above-stated analysis, carried out with the help of the morphological matrix, a new method of obtaining bimetallic products on the basis of the technology of casting with crystallization under pressure is offered, at which the working insert made of a sintered porous material is inserted into the liquid metal, placed into a closed heated matrix, is fixed in the desired position and the created bimetallic composition is subjected to joint stamping with holding under pressure until full crystallization of the base.

The aim of the work is to develop and study the combined process of manufacturing bimetallic products made of liquid metal and sintered powder materials on the basis of casting with crystallization under pressure.

2 Methods and Materials

As materials for the research we used: base material is cast aluminum alloy AK9ch (GOST1583-93), working layer is tin-bronze powder PA-BrO (GOST26719-85), modified with additives Sn and C, and iron powder ANS100.29.

The samples for the studies were bimetallic bushings of the following dimensions: D = 40–55 mm, d = 20–25 mm, h = 20–40 mm.

The technology of manufacturing bimetallic samples was as follows (Fig. 1): one-piece matrix 1 with coaxially installed mandrel 3 was heated to working temperature, having previously lubricated the working surfaces with non-stick coating.

The matrix was installed on the lower plate of press 2 and poured liquid metal base 6. Working insert 7 made of antifriction sintered powder material was installed on mandrel 3, introduced into the liquid metal with movable die 8, and joint stamping was carried out. Holding under pressure was carried out until full crystallization of the base material and penetration of the liquid metal into the pores of the powder material of the insert. The tooling material is 5XHM instrument die steel (GOST5950-2000). A composition based on the aqueous solution of colloidal silica was used as a non-stick coating.

An experimental batch of bimetallic blanks was produced on a special stand, stamping was carried out directly on the laboratory testing press PSU-125 with an effort of 125 ton-force (1250 kN).

From the previous works [7], it is known that the main technological parameters of the SLM (stamping of liquid metal) process are stamping pressure—P_s, temperature

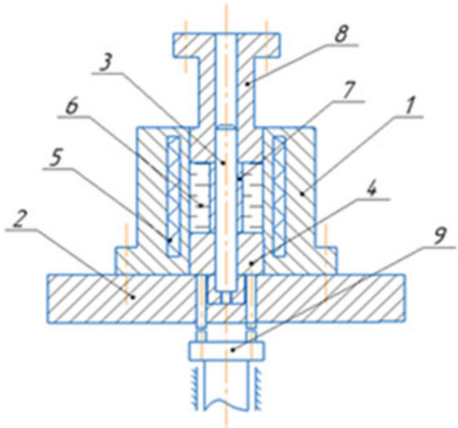

Fig. 1 Principle diagram of casting with crystallization under pressure of the liquid metal and the sintered working insert 1—matrix, 2—plate, 3—mandrel, 4—support, 5—heating element, 6—liquid metal, 7—working insert, 8—movable die, 9—ejector

of tooling—$T_{tool.}$, and time of crystallization under pressure—t_{cr}. Proceeding from this, one of the main tasks of the work was the search for optimal intervals of these parameters in relation to the pair of materials under study. The porosity of the powder blank during the study was constant—15%.

The experiment was conducted in the following technological modes: P_s = 0–100 MPa, $T_{tool.}$ = 450–850 °C, $t_{cr.}$ = 10–60 s. Microstructure of the contact layer was studied on the samples cut out from the central part of the blank in the longitudinal section. Cutting was performed on the "POLILAB R 30 M" low-speed precision cutting machine. Manufacturing of microslices was carried out with the use of the "POLILAB S50" pressing machine and the "POLILAB P12MA" grinding and polishing metallographic complex. Visual evaluation of the contact layer was conducted with the MIM-9 metallographic microscope using a digital camera. The method used is described in detail in [13, 14].

3 Results of Mechanical Tests and Metallographic Studies

Technological testing of shear strength of layer connection was performed on Ø55 × 20 mm ring-shaped samples cut out of the center of the workpiece on a Losen Hausen hydraulic test rig with a nominal force of 50kN. Mechanical tests of shear strength of the bimetallic product layer connection showed the following values: for the pair "AK9ch—PA-BrO9-1" within the range of 6.8–9.1 MPa. For pair "AK9ch—ANS100.29"—in the range of 42-60 MPa.

Hardness examination of the cross-section of the central part of the workpieces was carried out using the Vickers method (GOST 2999-75) on the ITV-10-MM hardness meter. The strength of aluminum after crystallization under pressure was 62.4–77.5 NV10, for sintered iron powder—189-227 NV10.

Figure 2 shows the microstructure of the contact layer of a bimetallic sample made of aluminum AK9ch and sintered bronze powder PA-BrO9-1.

Figure 3 shows the microstructure of the sample "AK9ch + ANS100.29" obtained under the following conditions: a—$P_s = 50$ MPa, $T_{tool.} = 500°C$, $t_{cr.} = 10$ s;b—$P_s = 100$ MPa, $T_{tool.} = 750°C$, $t_{cr.} = 20$ s.

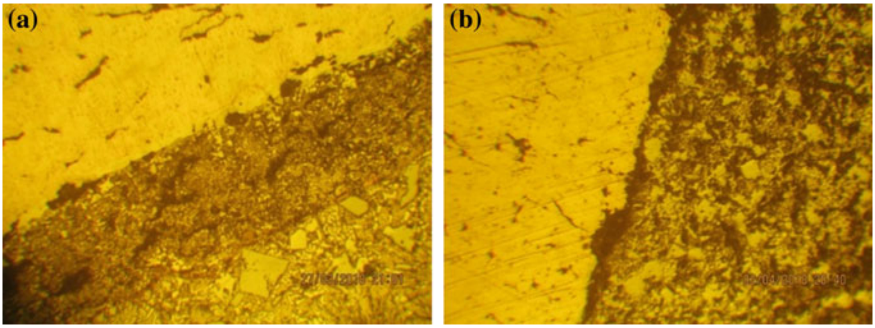

Fig. 2 Microstructure of the contact layer of the bimetallic sample "AK9ch + PA-BrO9-1": **a** with satisfactory solubility; **b** with a strongly pronounced contact layer zone. Magnification × 250

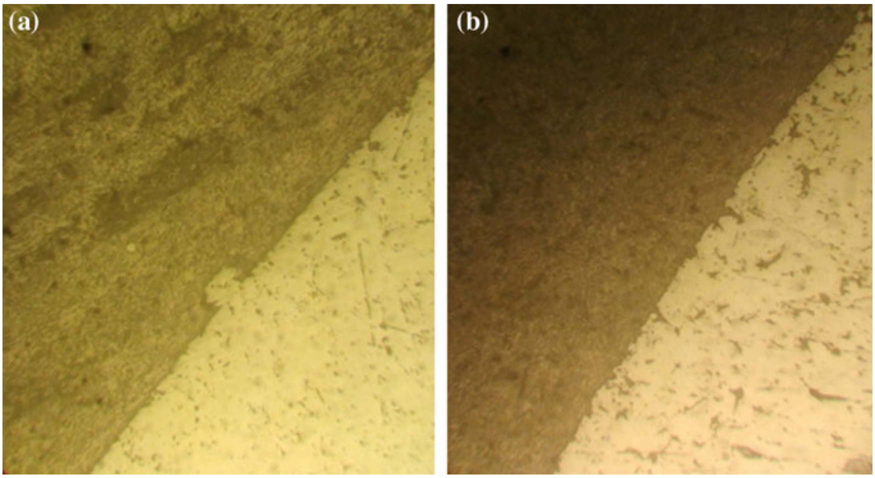

Fig. 3 Microstructure of the contact layer of bimetallic samples "AK9ch + ANS100.29": **a** with intermetallic layer zone; **b** with satisfactory area of mutual solubility. Magnification × 500

4 Discussion of Results

Shear strength of the layers in bimetallic pairs "AK9ch + ANS100.29" reaches an average of 50 MPa (Fig. 4).

The obtained result can be considered as a satisfactory result, comparable to the strength of bimetallic compounds of aluminum and steel obtained by other methods, such as welding.

Shear strength of the layers in bimetallic pairs "AK9ch + PA-BrO9-1" showed low values, which can be explained by worse weldability of materials in this pair, as well as the influence of graphite. For low-loaded bearings, this strength may be sufficient.

An increase in the hardness of aluminum is caused by pressure during its crystallization, which was observed in other works.

Studies of the contact layer microstructure have demonstrated satisfactory mutual solubility. In optimal modes of the process, penetration of aluminum into the pores of sintered iron was observed.

Optimal technological parameters of the stamping process of liquid aluminum, together with sintered iron powder, should be considered as the stamping pressure is 80–100 MPa, the temperature of the matrix is 700–800 °C and the time of holding under pressure is 15–20 s.

Fig. 4 Bimetallic samples obtained by joint stamping of liquid aluminum AK9ch and sintered powder ANS100.29

5 Conclusion

In conclusion, the most important results can be highlighted. A new method of manufacturing bimetallic products (plain bearings) on the basis of the technology of casting with crystallization under pressure has been developed [15]. The method includes pouring a liquid metal base in the cavity of a rigid matrix, placing a working insert made of a sintered powder material into the matrix after pouring the liquid metal base by immersion in a liquid metal and fixation in the desired position, the subsequent stamping with holding under pressure. The coefficient of thermal expansion of the base material is chosen by 20–30% higher than the coefficient of thermal expansion of the insert material, which contributes to the occurrence of compression stresses when materials of the base and insert cool down in the zone of their contact and provides increased adhesion. The introduction of the sintered powder insert into the liquid metal ensures destruction of the oxide film of the aluminum alloy formed during pouring of the metal, minimizes oxidation of the contact surface of the base and the insert material, and, consequently, increases adhesion and the quality of the product as a whole.

Mechanical tests of shear strength of the layers of bimetallic products “AK9ch + ANS100.29” showed strength within the range of 42–60 MPa. The achieved strength range is comparable with the strength values obtained by other methods of manufacturing bimetallic products. Therefore, the studied technology can be recommended for obtaining bimetallic products from other similar metals and alloys.

Further direction of the research on the proposed technology should be considered as modeling of thermal processes occurring at the boundary of the connected materials during their crystallization under pressure in the process of their joint stamping [16–18].

The resulting bimetallic blanks can be subjected to plastic deformation (hot bulk stamping, cold extrusion, rotational processing, etc.) to give them their final shape and dimensions. One of the effective methods of plastic processing is cold edge unrolling [19, 20].

Expansion of the product range obtained by the developed method can be the use of sintered working inserts with the gradient structure and special properties [21].

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