Alternative technology to manufacture bimetallic products by using self-propagating high temperature synthesis

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Abstract. Electric welding is usually used for surfacing metal products. This process may be laborious and time-consuming, which at the same time excludes welding jointing throughout the product surface. The productivity of powder tape surfacing is pretty low, up to 2.7 kg / h, with a melting rate of 13-15 min / h. The use of the self-propagating high-temperature synthesis for producing a liquid thermite alloy aimed at further surfacing throughout the metal surface of a detail can provide a cost-effective and viable alternative technology for manufacturing bimetallic products.

1 Introduction

To substantiate the alternative technology, it is necessary to study surfacing on the metal layer of the thermal alloy given by self-propagating high temperature synthesis, as well as to develop a laboratory installation for measuring the temperature fields in the mould at the previous heating of the charge, at the aluminothermic charge combusting, and at obtaining the synthesized thermite alloy.

In technology, termites are commonly referred to as powder mixtures of metals with metal oxides, the combustion of which generates a large amount of heat and results a high heating temperature, forms a melt from reaction products and powders of metallic filler [1–5].

The main purpose of termites in their use is the production of metals through the reactions, in which the metal is synthesized from the charge powders. Metals with a high heat formation of oxides with aluminum are required for the exothermic reaction. Metal oxide of low temperature such as iron oxide is a source of oxygen in the exothermic reaction.

The heat of exothermic reactions is effectively used in thermite welding. Termite welding is the process of welding metal details with a liquid metal of a given chemical composition obtained from an aluminothermic reaction.

Heat flow of a reaction is sufficient to heat the thermite surfacing alloy up to 3 134 K (the boiling point of iron) [4].

The actual task is to justify the technological parameters of the surfacing process of a metal layer, a layer of steel or cast iron, resulting from self-propagating high-temperature synthesis; to study the heating kinetics of the surfacing mould prior to the beginning of the melt synthesis, the temperature indices of the process components, the initial surface temperature of the surfacing layer; to develop a technology and a laboratory installation for more than 5 mm thick surfacing metal layer of steel or cast iron produced from a self-propagating high-temperature synthesis.

2 Results

The mould for surfacing consists of a sandy-clay shell with a lid. A metal layer for surfacing the thermite alloy is positioned in the mould. According to the model, a certain free volume is formed for the thermite mixture (Fig. 1).

The mould is dried at a temperature of 524 K for 1.5 hours in order to remove moisture. To control the temperature in the mould, thermocouples 4 (Fig. 2 a) are installed. The mould is filled with a thermite mixture 2, which is thickened on the vibrating table.
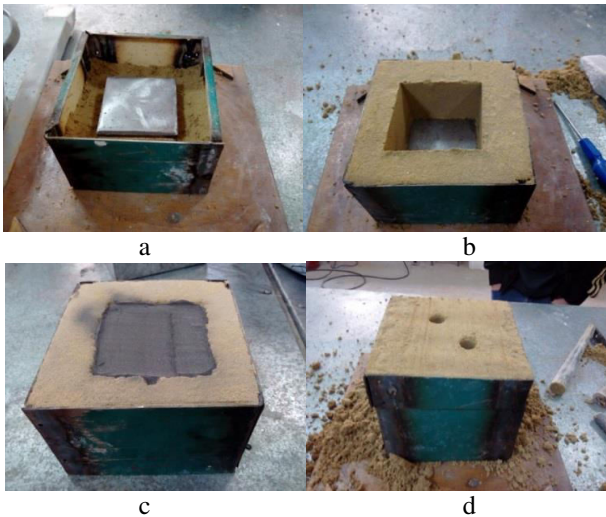
B

Figure 1 – Experimental mould: a – position of the metal base in the mould on the model; b – sandy-clay mould with a cavity for a thermite charge; c – condensed thermite mixture in the mould; d – mould assembly with an opening for arcing termite and venting gases
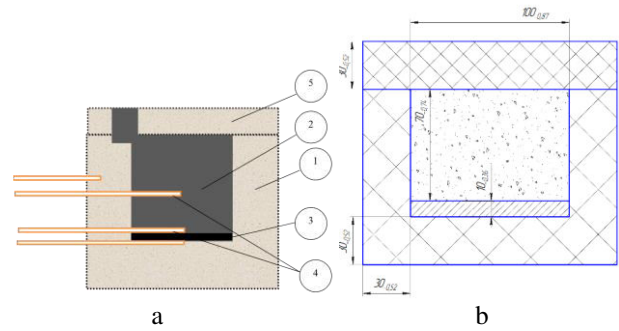

Figure 2 – Experimental mould: 1 – moulding mixture; 2 –termite mixture; 3 – metal base; 4 – thermocouples; 5 – mould lid

A laboratory installation has been designed and installed to study the kinetics of thermal processes in the form for exothermic surfacing. The lab unit includes: a laboratory muffle furnace, a surfacing mould, a controller with a recording device for the kinetic dependences of temperature variations, a set of tungsten-rhenium thermocouples with individual amplifiers and compensators (Fig. 3).
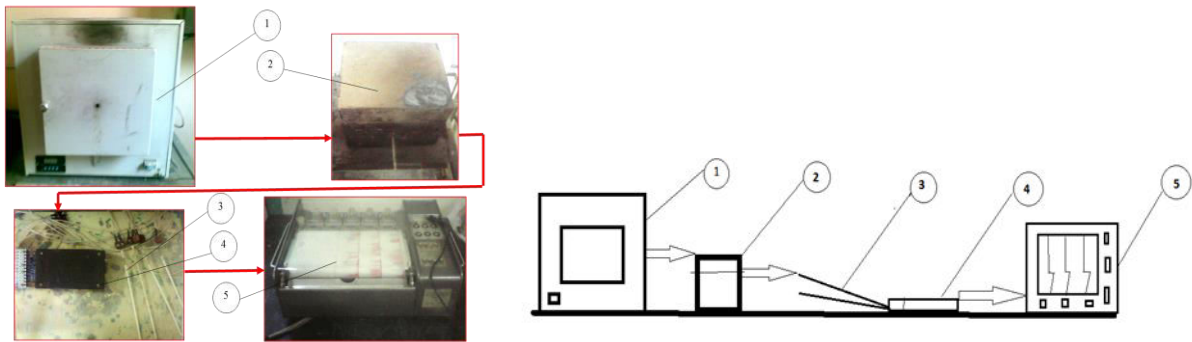

Figure 3 – Experimental laboratory complex: 1 – laboratory muffle furnace; 2 – experimental surfacing mould with thermocouples; 3 – tungsten-rhenium thermocouples BP 5/20; 4 – amplifier of the signal of thermocouples with compensators; 5 – high-speed self-writing device H32

Since the exothermic surfacing process generates high temperatures, tungsten-Rhenium thermocouples BP 5/20 with the maximum range to +2 774 K were used, which were insulated with ceramic tubes with two holes $d = 0.3$ mm. Thermocouples were connected to a high-speed self-writing device H 320-5.

Changing the voltage of the thermocouple indicator is a linear change in the temperature of the alloy. Since the voltage generated by the thermocouple is negligible, it is not possible to apply indicators to the tape of the recorder. The way out of this situation is to use an amplifier for a thermocouple. A circuit and a double-cascade operational amplifier LM 358 have been designed (Fig. 4).

The voltage gain can be increased from 50 to 200 times, depending on the position of the regulating resistor. On this basis, the resistance of the variable resistor R 3 is controlled by the graduated scale of the recorder tape. The amplifier tested with a thermocouple has an average sensitivity to the input voltage of 20 mV, resulting in an amplifier output of 3.8 V.
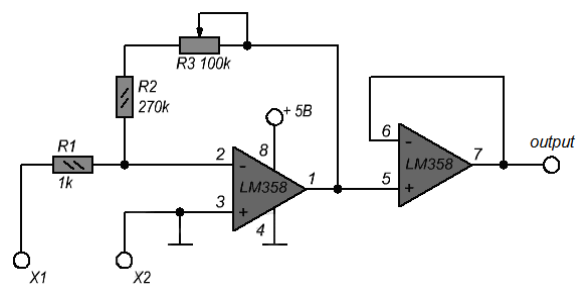

Figure 4 – Circuitry of the amplifier

When connected to the thermocouple, its negative output connects to the X 1 connector, and is positive to the X 2 connector. A 5 V power supply can be obtained using a voltage regulator 78 l05. It should also be noted that this circuit can be connected to a power supply of 12 V.

To study the thermal distribution in the surfacing process by casting the synthesized alloy, the thermocouples should be placed in the following areas of the form:

moulding mixture; under the metal base; over the metal base; in a thermal charge.

To determine the time of thermal distribution, the kinetic dependence of the filler form heating on time (temperature of the furnace 874K) was studied. Mould sizes were formed for the study (Fig. 2 b).

The prepared mould was heated in a laboratory muffle furnace preheated to a temperature of 874 K. The results are shown in (Fig. 5).
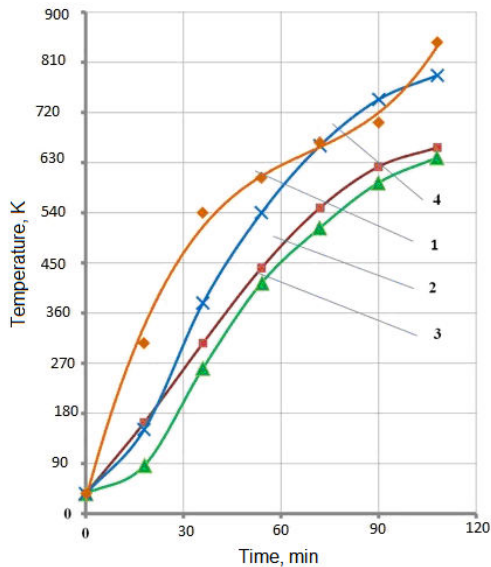

Figure 5 – The heating curve of the form per unit time:
1 – heating the walls of the mould; 2 – heating under the plate;
3 – heating of the thermal mixture over the plate;
4 – heating the thermal mixture in the middle

The graph shows that the temperature of the mould wall after its placing in the furnace is intensively increased. The dynamic temperature control up to 40 min is 13.5 K/min. The heating rate to 3.7 K/min varies from 40 to 80 min. When the mould is still in the furnace, the heating rate increases to 5.3 K/min. The increase in the heating rate of the moulding mixture is explained by the redistribution of thermal energy between the termite charge and the mould wall.

Thus, it is necessary to heat the mould for 110 minutes in order to achieve the temperature of the termite charge of 800 K.

Previous studies and theoretical calculations reveal that the main process parameter is the heating temperature of the termite charge in the exothermic casting process. The temperature of the metal base 630–640 K reached for a period of heating of the mould is sufficient for the process of surfacing.

In order to accelerate the mould heating time, when the exposed surfaces were directly contacted with the heated atmosphere of the furnace, a mould with an open metal base in the lower part (Fig. 6) was made, and the temperature in the furnace was raised to 924 K. The time for heating the surfacing mould to 874 K was reduced by 20 %, that is, to 90 min. However, it should be noted that the exposed surface of the metal base in the lower part of the mould significantly changes the self-propagating high-temperature synthesis process. When combustion of the thermite mixture in the 0.5 min from the start of the process is initiated, the temperature of the lower surface of the metal layer starts decreasing significantly to ambient temperature (4–5 ºC) and is kept for 3.5–4 s, as demonstrated in the thermogram Fig. 7 a.
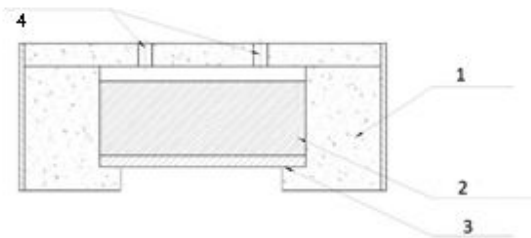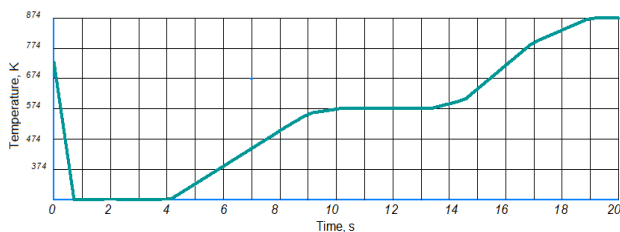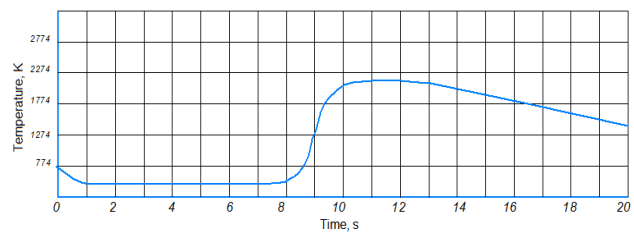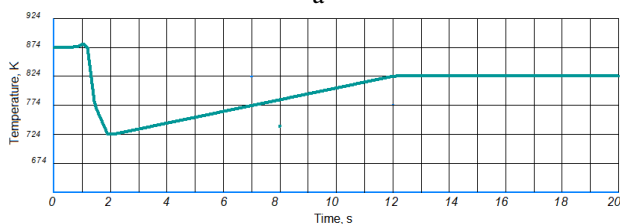

Figure 6 - A form with an open metal base in the lower part:
1 – moulding mixture; 2 – termite mixture; 3 – metal base;
4 – opening for ignition of a mixture and an output of gases
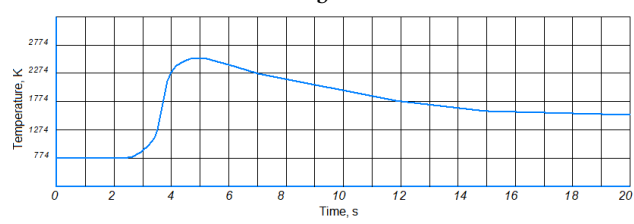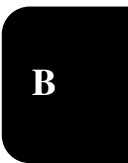

a

b

c

d

Figure 7 – Temperature distribution in exothermic casting a – lower surface of the metal base; b – upper surface of the metal base;
c – moulding mixture; d – process charge-alloy medium temperature

The total combustion time of the termite is 8.5 s, which is evident from the thermogram Fig. 7 b. After that the combustion front reached the surface of the metal layer and its temperature increased to 2 024–2 054 K within 1 s, that is, the termite began to melt. This temperature was kept for 5–7 s leading to the fusion of the liquid phase and the metal layer. In the 15.5 s from the start, the temperature of the layer decreased to the level of crystallization of iron and subsequently decreased at a rate of 354–374 K/s.

The temperature of the mould and its changes are shown in the thermogram Fig. 7 c. Within 0.5–1 s from the start of the process, the temperature decreased from 874 K to 724 K, and then at a rate of 284–286 K/s rose to 824 K and was kept until complete crystallization of the metal.

The temperature in the first 3–3.5 s did not change on the interface between the termite mixture and the moulding material at a point of a height of ½ of the bulk layer. When approaching the combustion layer to this point, the temperature rose and reached 2 474–2 674 K in 4–5.5 s, which was equal to the combustion temperature of the termite mixture. The allocated heat energy went on melting of the moulding material and its heating. A dense sand and slag deposition was formed on the inner surface of the mould, which kept the heat energy inside the mould.

It should be noted that the exposed lower surface of the metal base accelerates the preliminary heating of the experimental mould in the muffle furnace. At a time, there is cooling of both the moulding mixture and the metal base after the burning of the termite mixture. Similarly, the temperature of the mould from 874 to 724 K and the upper layer of the surface layer from 774 to 514 K is decreased. When the combustion process is completed, the temperature at these points is restored.

3 Conclusions

The required time for heating the mould to a temperature of 873 K is 110 min. However, raising the temperature in the furnace to 923 K causes the installation wear and the increase in oxidation of metal powders in the heating furnace. The use of the exposed lower surface of the mould adversely affects the self-propagating high-temperature synthesis process and the temperature of the metal base. This is due to the formation of air flow from the environment into the lower cavity of the form with the jet stream of gases emitted from the surfacing mould through the outlet in the lid during combustion of the termite mixture.

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