Electric treatment of alumina composite materials

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Abstract. A method of processing alumina composite materials using electric current is presented. Aluminum matrix composites based on aluminum alloy AK12 were obtained in a pass-through vessel with the addition of composite particles to the stream of molten material without the influence of an electric current and with the influence of a current. As a composite additive, graphite enriched with crystalline grade TG-1 and particles of titanium carbide (TiC) were used, the amount of the components being injected was 15 volume percent.

Measurements of the mechanical properties of the original AK12 alloy and composite material based on the AK12 alloy with the addition of composite particles carried out without an electric field and with exposure showed that the greatest increase in strength properties of alloys treated with an electric field was recorded for an aluminum matrix composite material with TiC particles, which amounted to 20% for ultimate strength and 24.5% for hardness. An increase in ductility was found in a composite material with a TG-1 composite additive, for it an increase in the relative elongation was 15.6%, while the electric current treatment of the composite material with a filler in the form of TiC did not lead to a change in the relative elongation of the sample material. In general, the increase in the strength properties of an aluminum matrix composite material with titanium carbide particles (TiC), after it was treated with an electric current, turned out to be slightly larger than that of an aluminum matrix composite material with particles of TG-1 enriched crystalline graphite. The physical mechanism of the influence of electric current on the properties of ALCM is given.

Keywords: electric current, aluminum matrix composites, mechanical properties, dispersed hardening

Introduction

The development of modern technology requires a qualitative improvement in the technical characteristics of machines and mechanisms, which can be ensured only under the condition of creating advanced manufacturing techniques for fundamentally new structural materials and their integrated use. At the present stage of development of engineering and technology, the improvement of methods for producing metal matrix, dispersion-strengthened composite materials (CM), as materials with reliable performance properties, is becoming important [1,2].

One of the promising directions in the technology of creating composite materials with a metal matrix...
is the use of the effects of external fields of various physical nature — ultrasonic, electromagnetic, and also elements of plasma technologies [1–8]. As it was shown in [9-16], the use of electromagnetic effects at the stage of modifying aluminum alloys, cast irons, steels, as well as at the stage of its crystallization during casting and thixolite allows reducing the grain size of the α phase and preventing the development of dendritic structure, increasing density and strength alloy, reduce porosity, increase its hardness. Also, the impact of the electric field is used in the preparation of aluminum matrix composite materials [6-8].

Experiments and results
The purpose of this work was to determine the degree of influence of electrophysical treatment of a composite material based on AK 12 alloy on its mechanical properties. The processing of the composite material based on the alloy AK12 with the electric current in the pass-through capacitance was carried out according to the electrical circuit shown in Figure 1.

Figure 1. Electrical circuit of the experimental setup: 1 - welding transformer,  2 - half-wave rectifier, 3 - LC-filter with measuring instruments, 4 - through-passage reservoir with liquid alloy.

An aluminum matrix composite material (ALCM) (Figure 1) based on an aluminum alloy AK12 was obtained by adding particles of a composite (CP) to the stream of a melt. As the composite, graphite enriched with crystalline grades TG-1 and particles of titanium carbide (TiC) were chosen. The input components were 15 percent by volume. Two series of experiments were done: obtaining CM without electric field and with electric field.

Voltage was applied to tungsten electrodes (E, Figure 1) with a diameter of 6 mm, which are located in the internal cavity of the passage capacitance 2. An induction-capacitive LC-filter 3 with measuring instruments, a half-wave rectifier 2 made on a semiconductor power diode of type D151-160, and a welding transformer 1 of an alternating current brand TDM-161U2 were connected to the electrodes. This scheme made it possible to obtain direct electrical contact with a liquid alloy flowing through a through-passage reservoir (Figure 1, position 4). The values of inductance and electric capacitance of which the rectifier LC filter consisted were selected in such a way that the value of the ripple factor was 1.5. The used value of the pulsation coefficient was chosen to optimize the processing of the liquid alloy, taking into account the phenomenon of polarization of the electrodes. The specific power of the electric current was calculated by the power supplied to the electrodes, referred to the mass flow rate of the liquid composite (kg / s), poured from the pass-through capacity into the molds. The value of specific power for a given passage capacity was 650 ... 663 J / kg.
Measurements were made of the mechanical properties of the original AK12 alloy and ALKM on the basis of the AK12 alloy with the addition of composite particles, carried out without an electric field and with an impact, the results of which are presented in Table 1. It was experimentally proved that the greatest increase in strength properties of untreated alloys (table 1) was recorded in ALCM with TiC particles, however, the relative elongation for CM with TG-1 was greater in value than CM with TiC. The impact of the electric field led (Table 1) to an increase in the strength properties and relative elongation of CM with TG-1, but the values of the strength characteristics of CM with TG-1 were less than those of CM with TiC.

Table 1. Data on the effects of treatment with an electric field on the mechanical properties of CM.

|                | Original raw alloys | Electric field treated alloys |
|----------------|---------------------|------------------------------|
| Mechanical properties of alloys | AK12 | AK12 + TG-1 | AK12 + TiC |
| $\sigma_{B}$, MPa | 149 | 161 | 182 |
| $\delta$, % | 5.1 | 9.6 | 8.2 |
| HB, MPa | 5.2 | 4.9 | 5.3 |

These changes in the mechanical properties indicate the influence of the electric field of the current on the process of forming the interface between the metal matrix and the dispersed inclusion. Hardening the interface structure causes an increase in strength of the CM structure.

The effect of the electric field of the current on the metal melt and its components is ambiguous. A number of physical phenomena occur that affect the intensity of the interaction between the composite filler and the liquid matrix. In our opinion, the action of the electric field of the current on the formation of the structure of the metal-matrix composite material can be represented by the following steps:
- set the stationary mode of flow of current in the melt containing the composite filler;
- particles of the dispersed material (DMP) under the influence of an electric field interact with the melt and the interface begins to form;
- as a result of the flow of electrical contact, surface phenomena, the charge of an electrical double layer that occurs at the interface of a metal melt with particles of a composite filler introduced into it increases, and qualitative changes of the interfaces occur.

To solve the problem of the further development of promising methods for obtaining CM, in which electrophysical processing is applied, it is necessary to develop and use a physical model of the influence of the electric field on the formation of the CM structure. Formalization of the physical model will allow optimizing the modes of electrophysical processing of CM, taking into account the used alloy and composite filler.

The physical model, which can explain the appearance of the effect of an electric field, should, in our opinion, take into account the peculiarities of physical phenomena associated with mass transfer in a metal melt and the occurrence of polarization electric charges on the surface of composite particles. As metallographic studies have shown, a physical model can be applied to describe the processes occurring in CM when it is processed by an electric field, which is schematically shown in Figure 2.
Figure 2. Formation of interphase boundaries.

At the first stage (Figure 2, E = 0, position 1), when the electric field strength E is zero, the reinforcing filler 1 in the form of composite particles is distributed over the volume of the melt. There is a capture by particles of a filler of atoms of chemical elements from a metal melt. The force field of the solid surface of the particles arising from contact with the liquid alloy is weakened at the protruding ends of the composite particles [1, 2, 6–8, 17–20] and, therefore, the interfacial energy changes and the wettability of the solid phase of CM by the liquid phase of the matrix melt. As a result, particles of CM are captured by atoms of chemical elements 2 from a metal melt.

At the second stage (Figure 2, E ≠ 0, position 2), the electric field strength E is not zero, polarization charges appear on the surface of the composite particles and energy fluctuation W occurs. The probability of this fluctuation of energy W according to Einstein’s formula is equal to [17]:

\[ W = \exp \left( - \frac{A}{kT} \right) \]  

(1)

where A is the electrical energy of the composite particle, k is the Boltzmann constant; T is the temperature of the metal melt.

In this case [17] work A is:

\[ A = \frac{q_0 \varphi}{\lambda} \]  

(2)

where \( q_0 \) is the initial polarization electric charge (K\( \varphi \)), \( \varphi \) is the potential (V).

Then the volume density of the electric charge Q will be equal to
\[ Q = \frac{q_0}{V}, \quad (3) \]

where \( V \) is the particle volume of the composite.

Under the influence of the electron-ion flow in the melt created by an external electric field, on the surface of the particles of the composite 3 (Figure 2, \( E \neq 0 \), position 2), an additional electric charge \( \Delta q \) occurs. This leads to an increase in the bulk density of the electric charge \( Q \) of particles CM:

\[ \frac{dQ}{dt} = \frac{q_0 + \Delta q}{V dt}, \quad (4) \]

where \( \Delta q \) is the increment of the particle charge of the composite.

**Discussion**

Also as a result of the flow of electric current, Joule heat is generated in the matrix melt, which leads to the formation of convective currents (Figure 2, \( E = 0 \), position 4), which intensify the movement of CM particles in the melt. These movements of composite particles contribute to a more uniform distribution in the volume of the matrix melt of reinforcing filler.

At the third stage (Figure 2, \( E = \text{const} \), position 3), additional layers of metal ions 5 are formed on the surface of the charged particles of the composite under the influence of electrons and ions accelerated by the electric field, moving along the molten metal and causing an electric current. In this case, as is well known, the Joule heat value is proportional to the square of the current that occurs in the metal melt during processing. When the voltage is turned off (Figure 2, \( E = 0 \), position 4), that is, when the passing capacity with the melt is disconnected from the source, the system relaxes to a new equilibrium state. At this final stage, there is a merging of charged particles of CM with each other due to the interaction forces obtained due to the charges formed by ions on their surface. Due to this, there are spatial formations of filler particles 6, which serve as a “skeleton” for the formed structure of CM. This hardening of the structure causes the growth of mechanical and operational properties, treated with an electric field CM, which leads to the appearance of the effect of external influence (EE) forming the structure of CM.

The result of these effects is the improvement of the conditions for the formation of interfacial boundaries, which determines the conditions for the process of adhesion of the particles of the composite with aluminum alloy and contributes to the hardening of the structure of alumomatric CM. The above results on the effect of electric current on the properties of alumina composite materials are consistent with the results of research, which used the influence of electromagnetic fields, in particular, electric current on the properties of aluminum alloys, when the electromagnetic effect was in the processes of alloy modification and crystallization [9-16].

**Conclusion**

Thus, the electrophysical effect leads to an increase in mechanical properties due to the influence of the electric field on changes in the structure of the boundary layer formed between the inclusion of the composite and the metal matrix. The hardening of the CM structure is possibly due to physico-chemical phenomena occurring at the interface under the influence of an electric field. Using this method to obtain alumomatric CM will give an economic effect due to the hardening of the structure of the CM and increase the operational reliability of machine parts made of CM.
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