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IMPROVING THE MANUFACTURING TECHNOLOGY OF ALTI MODIFIER FOR ALUMINUM ALLOYS

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ABSTRACT

The paper presents the results of laboratory studies on the manufacture of AlTi grain refiner. The developed technology includes self-propagating high-temperature synthesis of Al3Ti from a titanium sponge and molten aluminum; mechanical grinding of Al3Ti; adding of ground Al3Ti particles into the aluminum melt. The modifying ability of the experimental AlTi modifier is not inferior in effectiveness of the AlTiB at the same titanium content in the modifiable metal.

Keywords: alloying, master alloy, grain refinement, AlTi, AlTiB, self-propagating high-temperature synthesis, SHS, titanium sponge, titanium aluminide, intermetallic compound, microstructure.

INTRODUCTION

The blank production of flat ingots for rolling and cylindrical ingots for pressing from aluminum wrought alloys is widely used in many fields of mechanical engineering, including aircraft industry and in space technology [1-6]. Therefore, the technological and operational properties of these ingots are subject to increased requirements, which largely depend on size of the grain and its uniform distribution in volume of ingot. This is achieved by modifying the aluminum melt with special master alloys - modifiers. The Al5Ti1B alloying bar [7, 8] of various manufacturers, such as KBM Affilips, LSM, KB Alloy, HOESH, Aleastur and others, obtained widespread application in the aluminum industry. The production of Al5Ti1B master alloy typically includes aluminothermic reduction of potassium hexafluorotitanate (K2TiF6) and potassium tetra fluoroborate (KBF4) with subsequent separation of salt and metal phases. Further, a bar stock with a diameter of 9.5 ± 0.5 mm is obtained from the melt of master alloy using continuous casting and rolling technology, usually with Continius Properzzi equipment.

Al5Ti1B alloying composition contains two main types of intermetallic compounds: titanium aluminide (Al3Ti) with a particle size 30-100 μm and titanium diboride (TiB2) with a particle size 5-20 μm (Figure-1). These intermetallic compounds, after addition the master alloy into the aluminum melt, act as crystallizing nucleus and support to grain refinement of crystallized ingots. The average consumption of Al5Ti1B per ton of melt is 2 kg.

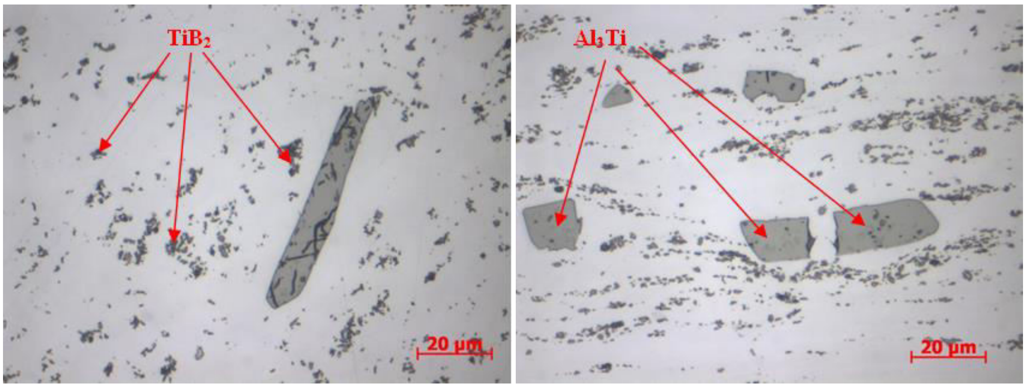

Figure-1. The macrostructure of Al5Ti1B alloying bar.

The main disadvantages of manufacturing and application of Al5Ti1B master alloy are listed below:

- the high cost of master alloy due to use of such expensive materials as complex fluorides of titanium and boron (K2TiF6, KBF4);
- the problem of uniform distribution of Al3Ti and TiB2 in the bar stock, in the melt and in the ingot during crystallization;
- the presence of large Al3Ti clusters with a size up to 100 μm in master alloy does not provide a sufficient number of crystallizing nucleus, leads to the loss of intermetallic compounds in ceramic foam filters, and also due to liquation of Al3Ti;
- Emissions of gaseous fluorides (BF3, HF) during preparation of master alloy and formation of second hazard class toxic waste of potassium fluoroaluminates during aluminothermic

reduction of complex titanium and boron fluorides.

The most complete information about the composition, properties and technological features of manufacturing and application of aluminum master alloys in Russia and abroad is posted in publications of V.I. Napalkov [9, 10].

One of the way for improving the manufacturing technology of Al5Ti1B master alloy is dissolution of a titanium sponge impregnated with molten potassium tetra fluoroborate in liquid aluminum [11].

MATERIAL AND RESEARCH METHODOLOGY

The purpose of this research is to develop a manufacturing technology of AlTi modifier with an average Al3Ti particle size from 5 to 15 µm, possessing the same modifying ability as AlTiB master alloy at the same titanium content in modifiable metal.

At present time, the AlTi alloying bar is practically not used for modification of aluminum and its alloys, due to the increased consumption to achieve effective grain refinement of crystallized metal. In practice, a tablet mixture of titanium and halide-containing fluxes with a weight ratio of 4 to 1 has become widespread [12], but this is difficult to use in the technology of continuous casting of ingots.

In the known Al5Ti1B master alloy the main function of grain refinement during metal crystallization is performed by TiB2 particles with size of 5-10 µm. Therefore, to ensure the modifying ability of AlTi modifier at the level of AlTiB master alloy, it is necessary to find an effective solution to reduce Al3Ti particle size in the AlTi compound from 20-70 µm to a size of no more than 10 µm. As such a solution, AlTi modifier manufacturing technology was proposed and experimentally confirmed. This includes the following basic operations [13]:

- obtaining an AlTi alloy with a Ti content of 30-37 Wt% by the method of self-propagating high-temperature synthesis (SHS) at an initial aluminum temperature of 800-900 °C (Figure-2, where the region of the desired alloy concentration is highlighted in red). The basis of this alloy is Al3Ti, the titanium content of which is 37.2 Wt%;
- mechanical crushing and grinding of the obtained alloy to particle sizes less than 10 microns;
- obtaining AlTi modifier by adding the obtained Al3Ti particles into the aluminum melt;
- crystallization of the melt in bar form.

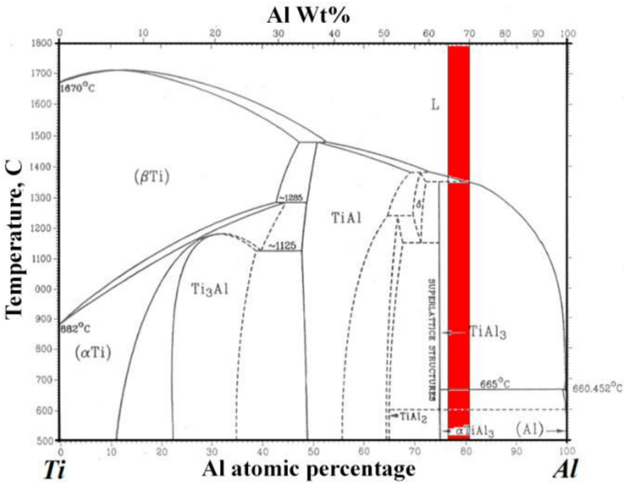

Figure-2. Phase diagram of Al-Ti system [14].

To obtain an AlTi alloy with a Ti content of 30-37 Wt% a titanium sponge was used as a feedstock. The estimated amount of titanium sponge was placed in a heated crucible and filled by molten aluminum. The temperature of the feedstock, at which SHS process begins ranges from 800 to 900 ºC and then increases to 1350-1400 ºC. The duration of this process is 1-2 min.

The X-ray phase analysis of the AlTi alloy was realized on a Shimadzu XRD-7000 automated X-ray diffractometer in Cu Kα-radiation. Radiographs were taken on powders in the range of angles 2θ from 5º to 70º in increments of 0.03 deg. The scanning speed was 1.5 deg/m. Then, the obtained results were processed using an information retrieval system for X-ray phase identification of materials combining qualitative and semi-quantitative analysis (using the "corundum numbers" method).

The results of X-ray phase analysis confirmed that the basis of SHS products is Al3Ti compound with a small admixture of aluminum.

Studies of the microstructure of alloy based on Al3Ti and AlTi master alloy was realized on micro analyzer Superprobe JXA-8200 (Jeol Ltd., Japan) staffed by a scanning electron microscope of high resolution and energy dispersive spectrometer (EX-84055 MU).

It should be noted that methods for producing Al3Ti using self-propagating high-temperature synthesis (SHS) are known [7, 15-17], but they are based on use of aluminum and titanium powders mixture and do not involve the use of a lump titanium sponge and aluminum melt.

RESULTS AND DISCUSSIONS

The Figure-3 shows the microstructure of Al-33.8%Ti alloy obtained by high temperature synthesis. The microstructure of the alloy is represented by three main phases: the base is an Al3Ti intermetallic compound (1) with a particle size of 5 to 7 µm; yellow inclusions (2) are particles of an intermetallic compound of titanium and aluminum of an intermediate composition AlTi1.25. The third phase (3), highlighted in blue, is aluminum located mainly along the grain boundaries of Al3Ti.

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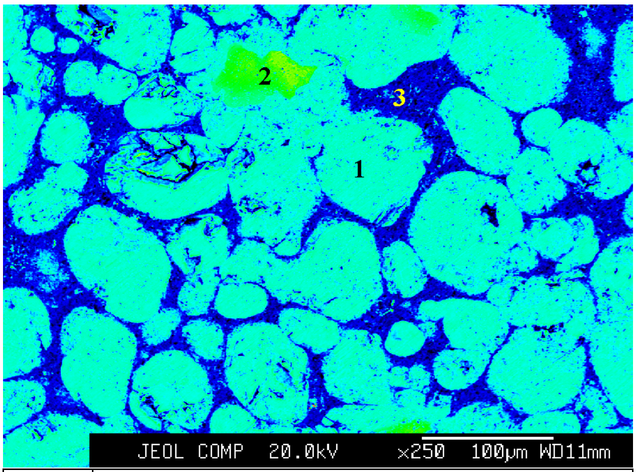
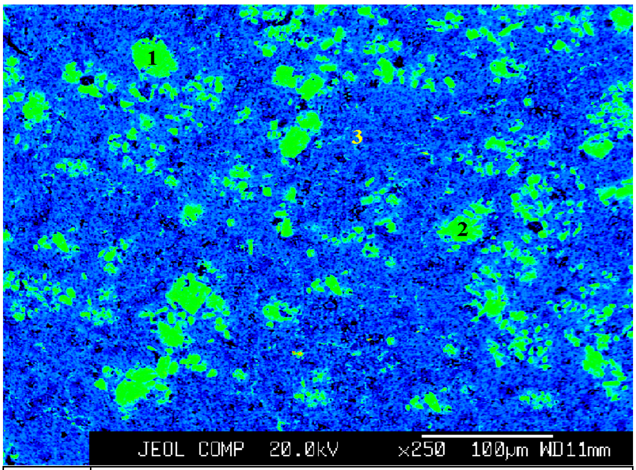


Zone	Content of elements, Wt%		
	Al	Ti	Si
1	62.995	36.586	0.419
2	31.160	68.840	-
3	99.264	-	0.736

Figure-3. The results of X-ray spectral analysis of main phases of the Al-33.8%Ti alloy.

Further, ingots from the obtained AlTi alloy were grinded and milled in an AGO-2 planetary mill to a particle size of approximately 8 μm. Then powder was dissolved in a melt of aluminum and sodium fluoroaluminate (NaFxAlF3) at a temperature of 830-850 °C. During melting, the melt was mechanically mixed for 10 minutes. Then sequentially kept for 60 minutes and cast into bars.

The Figure-4 shows the microstructure of manufactured Al–5%Ti master alloy obtained by addition into the aluminum a powder of Al-33.8%Ti alloy with an average particle size of 8 μm. This alloying composition has a dendritic and fragmentation structure of Al3Ti particles several microns in size. Agglomerates of Al3Ti particles are also predominantly rounded form with a size of several tens of microns, which is the main factor that reduces the modifying ability of the Al-Ti master alloy.



Zone	Content of elements, Wt%		
	Al	Ti	Si
1	63.132	36.618	0.250
2	64.679	35.321	-
3	100.000	-	-

Figure-4.

Table-1. The results of modifying ability test for Al-5%Ti and Al-5%Ti-1%B master alloys.

Sample	Raw material weight, g	Modified Al weight, g	Master alloy quantity, g	Master alloy type	Temperature, °C	Ti content in modifiable metal, %	Grain amount per 1 cm2 of macrosection
1	300	293	initial Al		740±10	-	32
2	300	295	0.295	Al-5%Ti	735±10	0.005	840
3	300	289	0.287	Al-5%Ti-1%B	740±10	0.005	812

1	2	3

Figure-5. The macrostructure of Al modified by Al-5%Ti and Al-5%Ti-1%B master alloys: 1 - initial Al; 2 - Al-5%Ti; 3 - Al-5%Ti-1%B

Amount of aluminum grains per 1 cm2 of the microsection was calculated at a Ti content of 0.005% in modified metal. Table-1 and Figure-5 shows that the experimental Al-5%Ti master alloy is not inferior in effectiveness to Al-5%Ti-1%B.

CONCLUSIONS

The result of laboratory studies is practice application of manufacturing technology of AlTi modifier using a titanium sponge [13-19], which allow to avoid the use of such expensive materials as complex titanium and boron fluorides (K_2TiF_6, KBF_4). Manufactured AlTi modifier has Al_3Ti intermetallic compound size up to 15 µm and a similar modifying ability as the well-known AlTiB master alloy with at the same titanium content in the modifiable metal.

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