Titanium Aluminide Producing in Chamber Electroslag Remelting Furnace

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Principal possibility of manufacturing of ingots of intermetallic compounds on TiAl base by the method of electroslag remelting in chamber furnace under active flux have been examined. Obtained ingots have typical for cast material structure and increased porosity (up to 15%). Cast metal has high chemical and structure homogeneity. The influence of high-temperature sintering under external pressure for treatment of such materials as titanium aluminides with low plasticity was studied. Described technological schemes may be used to produce of part with necessary shape, that may be subjected to following processing with using of traditional methods.

One of most perspective directions in the field of development of titanium alloys, with high strength and simultaneously with high thermal stability widespread in the world in last years is the development of alloys on the base of intermetallides Ti_3Al and $TiAl$ .They may be used in aircraft engines, explosion engines and as material for structural applications for static loading in high-temperature environment [1,2]. Intermetallides of $TiAl$ system are more light than nickel and titanium superalloys, they don't demand the protection from high-temperature oxidation, more cheaper and have rather high strength (ultimate tensile strength at 1473 K is more than 100 N/mm^2). They may be the competitors to nickel superalloys not only for aerospace applications, but in other branches of industry. [3,4]. Main disadvantages of titanium aluminides are the low plasticity, that is not correspond to necessary level of fracture toughness, and difficulties of processing of parts with complicated shape [5].

Wide application of alloys on TiAl-base is restrained by the absence of effective and non-expensive technologies of their manufacturing. Producing of TiAl-based alloys deals with difficulties, connected with differences in melting and evaporation temperatures and densities of components. Technologies of their manufacturing is very complicated and multi-stage. For example it is known the technological process of alloy (47-52)% Al- Ti – (1-2)% (Hf,V,Mn) that includes preliminary malting, 3-5 repeated melting in electric arc furnace with non-consumable tungsten electrode in argon atmosphere and final melting in suspended state with casting in copper mould [4].

Methods of powder metallurgy in combination with mechanical alloying demands very prolonged grinding of components and prolonged treatment at high pressure and temperature.
In current time there are small quantity of publications about application of technologies of especial electrometallurgy, electroslag remelting in particular, to produce the alloys of Ti-Al system. Development of rather simple and non-expensive methods of Ti-Al system intermetallides is very actual, but not solved problem now.

Analysis of technological possibilities of ESR process permits to make an assumption concerning possibility of its application for Ti-Al alloys manufacturing. In current work the results of using of chamber electroslag remelting process for this purpose are described.
Electroslag remelting was carried out in chamber ESR furnace A-550 [6], in copper water-cooled crucible 115 mm in diameter and 450 mm in length. Water-cooled chamber was mounted directly on the top of the crucible. System was designed with corresponding sealing to provide vacuum or excessive pressure of gases in working space. Before melting the chamber was vacuumed, and after that filled by argon. During melting the excessive pressure of argon 15 kPa approximately was maintained to compensate the leakage through different seals.

To cary out the experiments, the combined titanium-alumimium consumable electrodes were used. In first series of meltings titanium part of electrode was made from pressed rectangle blocks 30x40x200 mm of titanium sponge (TG-120 grade). Average density of pressed material was 2810 kg/m^3. Aluminium part of electrode was made from electrotechnical aluminium plates.
In second series of experiments titanium part of electrode was made from block of titanium rods 16 mm in diameter of VT1-0 grade.. Aluminium part of electrode was made from electrotechnical aluminium rods with triangle cross-section. This rods were mounted uniformly around titanium part of electrode.

The powder of CaF_2 with high purity and chips of metallic Ca were used as the base of flux. CaF_2 was annealed at temperature 973 K during 3 hours. Flux was melted directly in crucible with using of "solid" start. The calcium evaporates from the mixture CaF_2 - Ca during its melting and vapors of calcium decrease the partial pressure of oxygen and nitrogen above the slag pool to the magnitude 10^{-13} kPa.

Manufactured ingots had smooth lateral surface and porosity in top part of ingot. Inner surface of pores is clear and has not the differences in color with another metal. Therefore there is not the oxidation inside the pores. Obviously porosity has shrinkage nature. Metallographic investigations show that metal of ingot is rather uniform. Inclusions of aluminium and titanium are absent. Traces of cutting tool on the surface of machined ingot show that metal has residual plasticity at room temperature, but chips, formed during cutting have the appearance of uniform powder with bright faces. Phase composition of material was investigated by the method of X-ray structural analysis. Analysis of obtained results shows that main phase is the titanium aliminide TiAl. But some of reflections on difractogram could not be identified as belonging to TiAl. Most probable second phase is $TiAl_3$. This conclusion is confirmed by the results of metallographic analysis that determines the presence in structure of alloy matrix the small volume (2-5% of sample section surface) of second phase precipitations. They are located on boundaries of dendrites of matrix phase. Measurement of density and resistance to high-temperature oxidation shows that obtained material has the magnitude of these characteristics, corresponding with published earlier for γ-titanium aluminide.

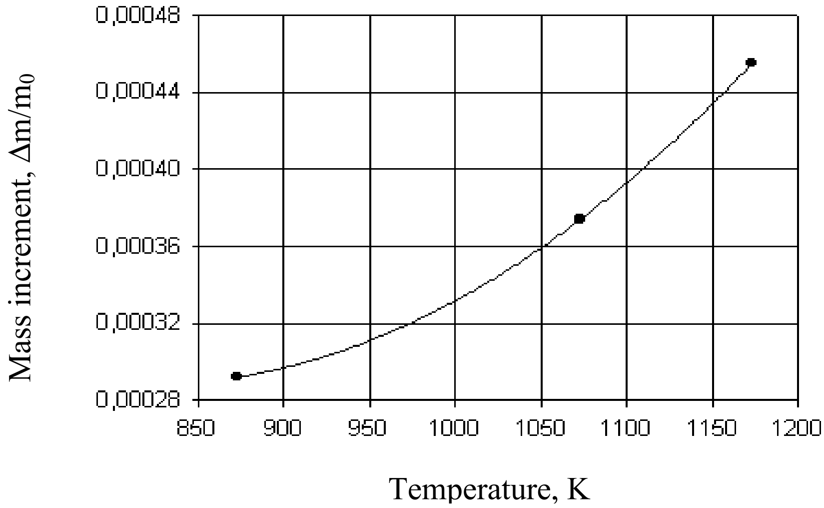
Obtained ingots were cutted along the central longitudinal axis. One half of every ingot was used to determine chemical composition (Table 1), another – to study the macro- and microstructure in cast condition.

Table 1 Chemical composition of experimental ingots

Ingot	Location of testing at height of ingot	Al content, %	Ti content, %
Ingot #1	Top	51,9	45,5
	Middle	52,2	46,13
	Bottom	43,6	54,5
Ingot #2	Top	54,5	40,0
	Middle	46,8	47,9
	Bottom	37,6	59,75

Resistance of TiAl to high-temperature oxidation is one of most important characteristics of material. Therefore the investigations of cast alloy characteristics at high-temperature gas corrosion were fulfilled. Experiments were conducted on samples at temperature 873, 1073, 1173 K with exposure 1-5 hours. Previously the weight of sample was determined, after that it was placed in heated chamber electric furnace, subjected to certain exposure, cooled on air and weighted again. Due to high porosity of samples there is not the possibility to measure the true area of oxidized surface of sample. Therefore the relative mass increment $\Delta m/m$ was determined for every sample and the graph of relationship between this characteristic and temperature of process was built for duration of exposure 5 hours. (Figure 1).

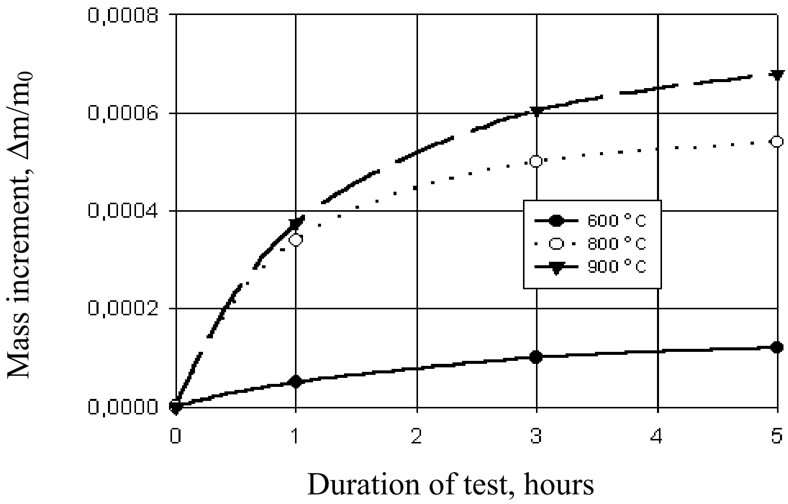
Figure 1 Dependence of mass increment on temperature of experiment (exposure 5 hours)



As we can see from the Fig. 1, this dependence may be approximated by exponent and acceleration of oxidation begins at temperatures more than 1073 K. This data is an a good agreement with results, obtained by other investigators [7].

Kinetic dependencies of mass increment at constant temperature (Figure 2) show that kinetic of oxidation has the damping character and type of dependence is close to parabolic. It is the evidence of protective properties of forming oxide film. Films of this type provide high resistance to high-temperature oxidation.

Figure 2 Kinetic curves of mass increment at constant temperature 873, 1073, 1173 K



Obtained ingots have high porosity and brittleness and they can not be used directly for producing of different parts. This material may be considered as semi-product. Therefore on next step of investigation the attempt to investigate the effect of treatment by high pressure at increased temperature on structure and properties of TiAl was made. Peculiarities of behavior of materials of this type at temperature-deformation influence are investigated insufficiently now, but results of preliminary investigations give the evidence of possibility to increase the complex of mechanical properties in result of such treatment.

In order to do this, the material of ingots was subjected to grinding in ball mill to the powder with particle size 3-7 microns. Plates 3x10x40 mm in size were made from the powder by pressing. After that they were subjected to sintering at temperatures 1533 (regime 1) and 1693 K (regime 2) and at two-step regime (2 subsequent treatment at 1533 and 1693 K with intermediate cooling) (regime 3). In all cases specimens were cooled after sintering with furnace (cooling rate 80-100 K/hour). Samples after sintering at 1693 K had the traces of partial melting, despite theoretical temperature of solidus line is equal to 1723 K. It may be explained by the influence of pressure (500 kgf/cm^2), that may cause the decreasing of phase transformation temperature.

Specimens, sintered at different regimes were subjected to phase X-ray analysis, microhardness measurement and microstructure examination. All specimens have two-phase structure with residual porosity. They consist of mixture of γ and α_2 phases. The most coarse precipitation of α_2- phase (30-35 microns) was formed in specimens, sintered in accordance with regime 1. It is 3 times higher then after regime 2 and 2 times higher then in specimens sintered at regime 3 (size of $TiAl_3$ precipitations 15-20 microns). These samples have large number of fine pores and microhardness of them is decreased. The minimal porosity was found in specimens after regime 2. They have most fine precipitations of second phase (5-10 microns). The refining of precipitations may be caused by process of phase transformation during the partial melting of material at high temperature, crystallization of molten metal and decomposition of solid solution during cooling. Recrystallization of particles, subjected to cold working hardening during mechanical grinding may take place too. These complex processes causes the changes in structure of sintered material.

To confirm the assumption concerning the phase composition of sintered specimens, the X-ray analysis was carried out. In sintered material after all regimes the considerable quantities of oxides and another impurities were not found. Only two main phases: $\gamma - TiAl$ and α_2 were determined.

CONCLUSION

Fulfilled work confirms the principal possibility of manufacturing of ingots of intermetallic compounds on TiAl base by the method of electroslag remelting in chamber furnace under active flux. Obtained ingots have typical for cast material structure and increased porosity (up to 15%). Cast metal has high chemical and structure homogeneity. It is confirmed by the results of chemical, X-ray, metallographic analysis and microhardness test results.

The effectiveness of using of high-temperature sintering under external pressure for treatment of such materials as titanium aluminides with low plasticity was confirmed. Described technological schemes may be used to produce of part with necessary shape, that may be subjected to following processing with using of traditional methods.

REFERENCES

[1] Abstract booklet. *The 9th World Conference on Titanium*. 7-11 June 1999, Sant-Petersburg, Russia.

[2] . Belov S.P., Brun M.Ya., Glazunov S.G and other. *Titanium alloys. Metallography of titanium and its alloys* – M.: Metallurgia, 1992. – 352 p.

[3] Bannykh O.A., Povarova K.B. Perspectives of development of heat resistant and oxidation-resistant alloys and intermetallic compounds // *New metallic materials: Transactions*. – Kiev: IEW named after Paton. – 1989. – P. 29 – 33.

[4] / Bannykh O.A., Povarova K.B., Braslavskaya S.B. Mechanical properties of cast alloys $\gamma - TiAl$ // *Metallovedenie i termicheskaya obrabotka metallov*. – 1996. – № 4. – P. 11–14.

[5] / Jamaguchi Masahary/ Investigation of microstructure of intermetallic compounds // *J.Jap. Soc. Heat. Treat*. – 1989. – 29, № 5. – P. 248 – 251.

[6] A.D. Ryabtsev, A. A. Troyansky, O. V. Tarlov, and other/ Investigation of possibility of titanium aluminide alloy producing by the method of electroslag remelting in inert atmosphere under “active” calcium-containing flux. // *Problem of SEM*. – 2000. – №1. – C. 75–78.

[7] Huang S.C., Chesnutt J.C. Gamma TiAl and its alloys.// *Intermetallic compounds*. -1994,-V.2.-P.73-88.