Research of the structure and properties of cermets based on nickel and aluminum oxide

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Abstract. In this work, the production of cermets in the system of nickel-aluminum alloy – aluminum oxide by the method of mechanical activation and spark plasma sintering was carried out. The analysis of the features of the microstructure of composites, phase analysis at room and elevated temperatures, as well as the dependence of the flexural strength on the temperature and composition of cermets are presented.

1. Introduction
Nickel and nickel-containing alloys are widely used in industry due to their outstanding characteristics, such as good mechanical properties, resistance to chemicals and heat treatment. Metal matrix composites provide an advantage over alloys, as they are especially suitable for assemblies requiring good strength at high temperature, good structural rigidity, dimensional stability and low weight. These composite materials also have a combination of a number of useful properties: resistance to corrosion, thermal fatigue, thermal shock, strength, toughness, metallurgical stability, processability, weldability, as well as their ability to withstand a wide variety of difficult operating conditions associated with high temperatures, high stresses as well as creep. Many researchers have shown that reinforcing additives such as silicon oxides, graphene, aluminum oxide particles; silicon carbide particles, tungsten, graphite, etc., can be easily incorporated into a nickel matrix to develop new composites.

The use of nanoparticles of refractory compounds in low concentrations for hardening metal and cermet composites is one of the ways to significantly improve the functional properties of new materials. Hardener nanoparticles, located on the grain boundary of the matrix, contribute to better sintering due to the formation of a developed interfacial layer, the appearance of additional contact surfaces. The use of nanoparticles in small amounts (not more than 0.1 %) contributes to their better distribution in the matrix with a minimum number of aggregates, which reduces the level of material defect [1–6].

In [7], materials based on the NiAl–Al₂O₃ system were obtained by the method of reaction synthesis with hot pressing. The authors note that the input of 15 % of the mass. Al₂O₃ in the alloy contributes to an increase in bending strength up to 765 MPa and crack resistance up to 9.67 MPa • m¹/², which is associated with better oxide distribution and grinding of matrix grains.
In [8], samples of composites NiAl–50 % vol. Al₂O₃. Flexural strength at nos such a material was 220 MPa, crack resistance 4.9 MPa • m¹/². Using the hot pressing method, NiAl / 20 (30) % vol. Al₂O₃ [9]. Flexural strength at nos such composites amounted to 635 and 456 MPa.

2. Materials and experimental methods
The following powders were used to manufacture cermet samples of various compositions (see table): PV-N70YU30 (20–63 μm, Ni – 69 %, Al – 30.5 %, Polema JSC, Tula), ChDA alumina (20 microns, 97 %, Donetsk Chemical Reagents Plant), spinel nanopowder (10 nm, 100 m²/g, > 99 %, RCTU, Moscow). For mixing, we used the Activator-2 SL planetary centrifugal mill (Chemical Engineering Plant LLC, Dorogino, Novosibirsk Region) with steel cups and balls with a diameter of 5 mm and a ratio of powder: balls = 1: 3, rotation speed disc 700 rpm. The introduction of spinel nanoparticles in an amount of 0.1 wt. % was carried out in isopropyl alcohol with the addition of 0.1 wt. % Oleic acid under the influence of ultrasound and continuous stirring with a paddle mixer. Extrusion and sintering was carried out by the electric spark method on a FCT-HP D 25 installation (FCT Systeme GmbH, Germany) in argon at a temperature of 1470 °C for 30 min and a pressing pressure of 50 MPa. Samples were obtained in the form of cylinders with parameters Ø 30 × 3 mm. The tensile strength was determined at room and elevated (750 °C) temperatures by the three-point bending method on the TestSystems-Vac-It universal testing machine (State Research Center Federal State Unitary Enterprise Keldysh Center, Moscow). The modulus of elasticity and internal friction were evaluated using an ultrasonic installation "Muse" at t = 20 and 750 °C. The microstructure was studied using a FEI Quanta 600 FEG scanning electron microscope (FEI, Netherlands).

3. Results and discussion
The microstructure of sintered materials NiAl-Al₂O₃ and NiAl-Al₂O₃-MgAl₂O₄ is shown. A sample containing spinel nanoparticles is characterized by finer grain and better uniform distribution of the oxide component.

\[ \text{Figure 1. Microstructure of composites: a – NiAl–35Al}_2\text{O}_3, \text{ b – NiAl–35Al}_2\text{O}_3–0,1\text{MgAl}_2\text{O}_4. \]

Figure 2 presents the results of XRD analysis of samples of the obtained cerments at 20 and 800° C. The main components at 20 °C in the material are alpha-Al₂O₃ and NiAl. At 800 °C, the picture changes due to the appearance of high-temperature Al₂O₃ phases, as well as Ni₃Al, NiO, and NiAl₂O₄ phases.

Based on the data of the above studies, as well as some other [10, 11], as well as on the basis of the results obtained by the authors of this article, the dependences of the flexural strength on the composition and temperature of the tests were constructed (figure 3). It can be noted that the trend curves of changes in the flexural strength of the cerments under consideration are the same in nature, depending on the ratio of the amount of Al₂O₃ to NiAl and the test temperature.

4. Conclusion
The effect of aluminum-magnesium spinel nanoparticles on the structure and mechanical properties of cerments in the NiAl–35Al₂O₃ system is studied. Found that the additive is 0.1 % of the mass. MgAl₂O₄
nanoparticles in cermet increase its bending strength at 20 °C and 750 °C by an average of 9%.

As a result of X-ray phase analysis at 20 °C and at 750 °C it was determined that the main components at 20 °C in the material are alpha-Al2O3 and NiAl. At 800 °C, the picture changes due to the appearance of high-temperature Al2O3 phases, as well as Ni3Al, NiO, and NiAl2O4 phases.

Figure 2. XRD-analysis of NiAl–35Al2O3 cermet results.

The analysis of the nature of the change in the mechanical strength of cerments in the NiAl–Al2O3 system at 20 °C and at 750–800 °C. There is a clear connection between the flexural strength of materials at nos and at high temperature with a ratio of NiAl/Al2O3.

Figure 3. Bending strength of different cerments vs. temperature.

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