A Study of the Modifying Influence of Nanoparticle Additives Produced by Plasma—Chemical Synthesis on the Structure of Cast Aluminum Matrix Composite Materials


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Received March 19, 2009

Abstract—The results of an investigation into the microstructure of composite materials based on an aluminum matrix reinforced by intermetallic phases, which are formed by in situ reactions in the presence of nanosize ceramic particles, are presented. The possibility of modifying and stabilizing the structure of such composite materials with nanopowder additives is determined.

DOI: 10.1134/S1995078009070143

INTRODUCTION

In recent years new approaches to synthesizing multifunctional composite materials (CM) based on different mechanisms and scale levels of matrix reinforcing have been developed. Such approaches can be clearly illustrated by the manufacturing process of cast aluminum matrix composite material with discrete reinforcement.

The structure and properties of such composite materials can be controlled if dispersed refractory fillers are introduced into the matrix from outside (ex situ) and if the reinforcing phases are formed directly during CM manufacturing as a result of an in situ reaction between the molten matrix and reaction-promoting additives (metallic powders Ti, Ni, Fe, Mo, etc., [1,2]). As is known, these additives form intermetallic phases with aluminum and they efficiently modify the cast structure of aluminum alloys [3]. We hope that nanosize refractory powders can be fruitfully used in modification. It is supposed that, due to their unique collection of properties (very high specific surface, energetic potential, and ability to self-organize), nanopowders can sufficiently influence the crystallization process and the formation process of the structural components of composite materials, including those which are produced by reaction casting. Early investigations show that the morphology and sizes of the reinforcing intermetallic phases which are formed as a result of exothermic in situ reactions vary greatly if the dispersion of basic components and casting conditions are changed [4]. For this reason composite materials such as the model ones are chosen when we estimate the modifying influence of nanosize refractory powders produced by plasma—chemical synthesis.

MATERIALS AND METHODS OF INVESTIGATION

The samples of composite materials were obtained by introducing the powder of reaction-promoting metals and nanosize refractory particles into a molten matrix. Technically pure aluminum AD—1 was used as a matrix, and as a filler we used titanium powder (with a particle size of less than 100 µm); nickel powder (with a particle size of less than 20 µm; and the powders of aluminum oxide, titanium carbonitride, tungsten, and a tungsten—carbon composition obtained in the thermal plasma of electroarc discharge in a jet-type plasma—chemical reactor. Air, nitrogen with methane added, and nitrogen—hydrogen and methane—air mixtures were used as plasma—generating gas. As a metal-containing raw materials, dispersed aluminum, dispersed tungsten oxide, and evaporated titanium chloride were used [5—7].

The powders obtained in plasma were studied in detail. The granulometric composition of the powders was determined by measuring the specific surface (by the Brunauer—Emmett—Teller (BET) method) and calculating the mean size of the particles. Particle distribution over the sizes was determined via statistic processing of the images obtained by electronic microscopy means (raster and transmission (REM and TEM methods)), as well as by using laser and X-ray diffraction over the sizes of the area of coherent scattering. The phase composition of the powders was determined by energy dispersive X-ray analysis, and oxygen and carbon admixtures were analyzed chemically using analyzers produced by Leco.

All powders are polydisperse. The particle distribution over sizes is close to logarithmically normal. The most typical curve of particle distribution
over sizes for the nanopowder of aluminum oxide obtained by the laser diffraction procedure on a Mastersize–2000 (Malvern) device is shown in Fig. 1. The shape of aluminum oxide and tungsten particles is close to spherical due to the fact that they are formed according to the vapor–liquid–crystal mechanism. The particles of titanium carbonitride have a pronounced cubic shape. In the composition of W–C, there are both spherical and faceted particles. Figure 2 depicts the general view of nanopowders of Al₂O₃, TiCN, W, and W–C produced by plasma–chemical synthesis.

There is typically an oxide film on the particles’ surface of tungsten powders. The summary oxygen content in this powder is 1.5–2.0 mass %. The powders of W–C are characterized by a complicated phase and chemical composition. The basic phases are as follows: W₂C, WC₋ₓ, WC, and C. The content of free carbon is about 4 mass %. The content of oxygen is less than 1 mass %. The main performances of the powders are presented in Table 1.

Figure 3 depicts the appearance of Ti and Ni powders, which are added to molten matrix in order to form in situ the reinforcing intermetallic phases. It can be seen that the powders have well-developed rough porous surfaces, which permits their use as a “carrier” introducing nanopowders into the melt [8]. The mixture of metallic powders and nanosize additives (Al₂O₃, W, TiCN, W–C) was processed in a mass-exchange device indented for preparing emulsions, suspensions, metallic sols, for mixing the liquids and loose substances, crushing, and chemical reactions promoted by means of electromagnetic action to working bodies (steel cylinders) and the processing product. The mixing lasted 10 minutes. In the end, the