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Advanced composite alloys for constructional parts of robots

D K Issin[1], Zh D Zholdubayeva[1], Y G Neshina[2,3], A D Alkina[3], N Khuangan[1] and G M Rahimova[1]
[1]Karaganda state technical university, Karaganda, Kazakhstan
[2]Tomsk State University, Tomsk, Russia
[3]Tomsk Polytechnic University, Tomsk, Russia
E-mail: 1_neg@mail.ru

Abstract. In recent years all over the world special attention has been paid to the development and implementation of nanostructured materials possessing unique properties and opening fascinating prospects for the development of technical progress in various fields of human activities. A special place can be given to the development of service robots, the market of which is actively developing. There is problem associated mainly with the lack of heat-strengthened alloys which consists in low thermal stability of the alloy properties under the conditions of elevated variable temperatures and loads. The article presents studies to assess the effect of composition, the amounts of refractory nanoscale particles and methods for their introduction into the melt on the structure and properties in nanostructured composite aluminum alloys. The powders of metals, alloys, as well as silicon carbide and aluminum oxide were used to produce the nanostructured powder composite materials. As a result of the research, NPCM compositions containing micro-size particles of transition metals that are carriers of nanosized reinforcing particles and initiators of the formation of an intermetallide of endogenous origin in a melt.

1. Introduction

The development of robotics creates the significant prospects for replacing the human in hazardous and difficult working conditions in the industry and will lead to the replacement of a number of professions that will eventually become history. Today there are the production facilities with a high level of automation where about two or three dozen people employs, and the rest of the staff is replaced by industrial robots and this is not uncommon. According to various estimates of experts in the field of robotics the level of production of industrial robots ranges from 20 to 30 billion dollars. While a smaller amount of them is allocated for service robotics. The main buyers and manufacturers of industrial robots are USA, Germany, Japan, South Korea, China. The world leader in production remains Japan, which owns 50% of the world market, about 20% in Germany, but in connection with the entry of China into the world market, the situation may change in the coming decades.

The development of robotics is a catalyst for the development of new industry 4.0. A special place can be given to the development of service robots, the market of which is also actively developing due to the enormous volume of various developments that will be so accessible in the next 10 years that every family in half the countries of the world will can afford to buy a service robot. These development prospects form the specific problems, in particular, one of which is the search and creation of new materials for the manufacture of constructional parts of robots. Materials must have a number of properties that allow them to be used in mass production at a low cost, but it should not be at the expense of their mechanical strength. The strength of the materials and their availability will

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make it possible to expand the range of their applicability and availability. There is no doubt that not only the development of materials of the new generation is essential, but it will be necessary to promote science in the field of nanotechnology, precision mechanics, electronics and optics. In our work, for further processing and production of constructional parts of robots we would like to touch on the theme of finding new composite materials based on aluminium matrix alloys, consider the methods of their casting and the melt of the particles of the reinforcing filler (short fibers, whiskers, particles), and the subsequent filling of the resulting liquid-metal suspension into a casting mold after cooling of which the required product is obtained.

2. Analysis of the problem

There is a small problem associated mainly with the lack of heat-strengthened alloys which consists in low thermal stability of the alloy properties under the conditions of elevated variable temperatures and loads. Therefore, the developments in the field of synthesis of composite aluminium matrix alloys (CAMA) are started and being actively implemented, the main feature of which compared with known ones, including high-strength alloys is the presence in the structure of artificially introduced or initiated as a result of exothermic reactions thermos table components that provide the required properties of the material, including at elevated (up to 200°C) and high (up to 400 °C) temperatures. The properties of CAMA are determined by the properties of the matrix material, properties and dimensions of the reinforcing ones introduced or initiated (obtained in-situ) into the melt of particles and the interaction between the matrix and the reinforcing particles. Ready-made micro- and nanoscale refractory ceramic particles (for example, SiC, Al_2O_3, Si_3N_4, A1N, B_4C, MgO), intermetallic compounds and other types of particles can be used as reinforcing complexes introduced into CAMA. Fundamentally important thing in obtaining CAMA is to ensure the wettability of the introduced particles with a matrix melt to form the stable adhesion bonds.

Three technological schemes of CAMA production are mainly used: introduction of particles into the melt under intensive mixing with the help of an impeller; powder technology; impregnation of dispersed particles or press molds with a matrix melt. Liquid-phase technology for the production of KAMA with the introduction of a significant amount (up to 20%) of micrometric refractory particles into the melt has been achieved to widespread industrial applicationы (MS 21, Duralcan, Science Application Intern. Corp. (USA), British Alcan, Talon Composites (England) and etc.). A number of companies, in particular Duralcan, supply the resulting alloys in the form of cast sections (billets), which are subsequently used as the charge materials in obtaining of cast products by various methods of casting. Depending on the composition of the matrix alloy, the composition and the amount of particles introduced, alloys with different complex of mechanical and operational properties are obtained, used for products of different purposes.

3. Materials and methods

The method of composite casting (Compocasting) includes mixing of reinforcing filler particles (short fibers, whiskers, particles) into the wide-interval matrix melt with a simultaneousgradual decrease in temperature and then pouring the obtained liquid metal suspension into the casting mold after cooling of which the required product is obtained. The method is developed on the basis of rheological casting (Rheocasting) created in the early 1970s by Fleming and others. The main advantage of the method is the possibility of introducing the non-wetting particles that are mechanically captured by the melt.

In recent years all over the world special attention has been paid to the development and implementation of nanostructured materials possessing unique properties and opening fascinating prospects for the development of technical progress in various fields of human activities. Despite a significant number of works of foreign researchers in which the attempts are made to theoretically substantiate the processes occurring in nanostructured composite aluminum alloys (NCAA), the theory of these processes has not been created. There are only separate attempts to explain the phenomena that occur in the NCAA in the process of forming their structure and properties.

The problem of developing nanostructured metal matrix compositional alloys is studied by many researchers in the world largest scientific centers, as well as in a number of Russian research and educational institutions. After analyzing the scientific papers [1–7], it can be noted that only a part of them is devoted to the development of casting composites, i.e. alloys with a level of casting properties, which allow obtaining from them the shaped cast products. In these works, the main requirement for such alloys and components is a certain level of tribological properties. The main methods of preparation of dispersed particles is the mechanical alloying, the main method for introduction into the melt is the mechanical mixing of compressed tablets or briquettes. The importance and effectiveness of the development of NCAA is confirmed particularly by the attention given to this problem abroad. Based on the results of works that was performed by us [8–11] on obtaining the NCAA on alloy A357basis, at SPbSTU*) jointly with Zvezda OJSC**) the studies have been conducted to assess the impact of composition, the amount of nanoscale refractory particles, and the methods of their introduction into the melt on the structure and properties of NCAA. One of the most serious problems in obtaining NCAA is the preparation of nanoparticles for introduction into the melt. In most cases, the nanostructured powder composite materials (NPCM) obtained by mechanical alloying consisting of particles of a metal carrier powder with nano-dispersed non-metallic inclusions distributed therein are used. It has been theoretically justified and experimentally proven that the properties of composites are increased with a decrease in dispersion of reinforcing phases to the nanometer level.

For the production of NPCM we used the advanced technology of activation mechanical alloying in high-energy mills (attritors) [8]. The powders of metals, alloys, as well as silicon carbide and aluminum oxide were used to produce NPCM.

NPCM (Cu + 4.5% Al_2O_3) was obtained by thermochemical method [9, 12] using aqueous solutions of copper and aluminum nitrates (Figure 1). This technology ensures the uniform distribution of nanoscale refractory particles in a micrometric basis directly during the synthesis of NPCM.

NPCM can be seen not only as a raw product in the production of NCAA, but also as an independent commodity product, which can be supplied to various manufacturers of products from composite metal-matrix alloys.

The composition of the parent alloy A357 (mass. %): 7.5 Si, 0.35Fe, 0.45 Mg, 0.02 Mn, 0.06 Ni, 0.03 Cu, 0.08 Zn, Al – the rest. The properties of as-cast parent alloy A357:$\sigma_{ultimate}$=155 MPa, δ = 3.5 %. In the first series of experiments, A357alloy (2 kg) was heated in the resistance furnace to 800 °C, the calcined all-purpose flux was mixed and removed, the crucible was transferred to the electromagnetic stirrer, 5% of NPCM (62.5% Cu + 28.1% Ni + 3.1% SiC) was introduced during the mixing with a plasma facility.

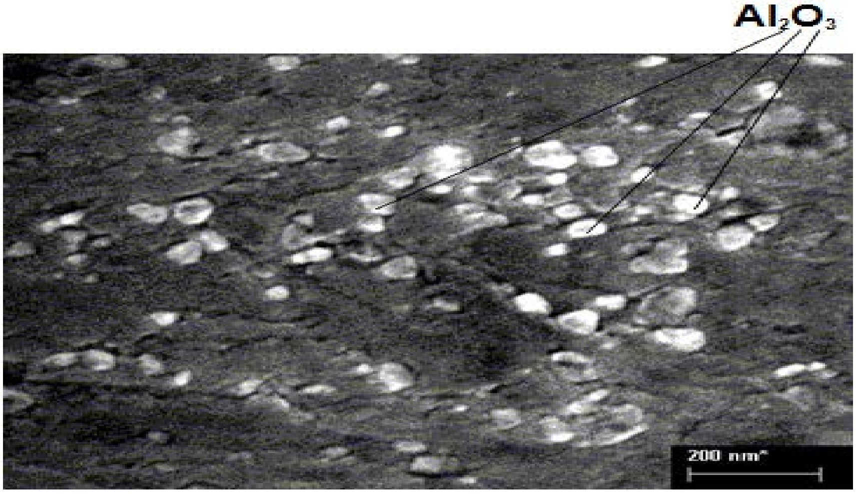

Figure 1. Structure of the NPCM Cu/Al2O3 (thermochemical method).

The duration of the NPCM introduction (work of plasma facility and stirrer) is 50...60 s, the temperature of the metal in the process of NPCM introduction dropped to 720...750ºC after which the casting mold was filled with samples with a diameter of 12 mm and a length of 100 mm. The NPCM calculated assimilation was 94% before heat treatment at the normal temperature $\sigma_{ultimate}$=280 MPa, δ = 3.5 per cent. After T6 at the normal temperature $\sigma_{ultimate}$= 390 MPa, δ = 7.5 %, at 350ºC-$\sigma_{ultimate}$=160 MPa, δ = 11%. Metallographic studies of the obtained A357 alloy (SiC) confirmed the presence of nanoscale SiC inclusions, the invariance of the phase composition and the dimensionality of these inclusions during the NCAA synthesis. In the second series of experiments, the conditions were identical to the first series, however, 5% of the NPCM containing 95.5% Cu + 4.5% Al_2O_3 was introduced into the melt with a plasma facility. The NPCM calculated assimilation was 92%, before the heat treatment at the normal temperature$\sigma_{ultimate}$= 290 MPa, δ = 4.5%. After T6 at the normal temperature, $\sigma_{ultimate}$ = 405 MPa, δ = 8.5%, at 350 ° C - $\sigma_{ultimate}$ = 165 MPa, δ = 12.5%. After T6 at the normal temperature $\sigma_{ultimate}$ =405 MPa, δ = 8.5%, at 350ºC-$\sigma_{ultimat}$=165 MPa, δ = 12.5%.

In the course of preliminary experiments, the method of introduction into the melt of NPCM with the help of the "flux-cored wire" variant (introduction of an aluminum tube filled with NPCM under the bath level in furnace) was also used when mixing NPCM into the melt with a mechanical stirrer (300 rpm) and then transferring the crucible with melt into the electromagnetic stirrer. The temperature regimes, composition and number of NPCM are identical to those realized in plasma synthesis. The NPCM calculated assimilation was 76%, before the heat treatment at the normal temperature, $\sigma_{ultimate}$= 205 MPa, δ = 3.5%, after T6 - 280 MPa, δ = 4.0%.

The plastic treatment of the resulting cylindrical cast sections (billets) in a liquid-solid state (585 ± 5 °C) confirmed the possibility of practically eliminating the initial porosity, realizing the process of liquid-solid molding (thixocasting) with the invariable distribution of nanoscale particles of the reinforcing phase.

4. Summary

It is possible to introduce the nanoscale reinforcing and modifying particles into the melt of NPCM, it can be a separate type of commodity product. The most promising are the compositions of NPCM containing micro-sized particles of transition metals that are carriers of nanoscale reinforcing particles and initiators of formation of intermetallicsof endogenous origin into the melt (in-situ process).The behavior of nanoparticles in the melt (agglomeration, dissolution, uniformity of distribution) during the introduction and mixing of particles, exposure, during the filling of the composite into the mold and the formation of the casting product, the influence of the amount of phase composition, the conditions of introduction of nanoparticles into the melt on the properties of composites are virtually absent or debatable. The use of wide-interval alloys as a basis for the production of NCAA allows to intensify the effect of wettability of particles by melt during its mixing in the liquid-solid state, ensure the uniformity of their distribution in the volume of melt and ingot (casting), use the melt in the liquid-solid state to produce the dense products by thixocasting method. Two-plane electromagnetic stirring of melt, regardless of the technology of nanoparticle introduction into the melt and the pre-mixing process, provides the possibility of mixing the melt in both liquid and liquid-solid states. The process of plasma injection of NPCM into metal melts in combination with two-plane electromagnetic stirring has a number of advantages over other methods of obtaining NKAA, but requires optimization of operating modes depending on the type of matrix alloy, the composition and number of introduced particles, the volume of production of billets and shaped products, and also requires the feasibility study of advantages over other methods of NKAA obtaining in specific production situations. In order to obtain the NCAA with improved performance properties, it is necessary to realize all the technological possibilities for improving the properties of the matrix alloy, in particular, nanomodification and nanoalloying, external influences on the liquid and crystallizing alloy. The nanostructural composite metal matrix alloys are one of the most promising construction materials of the future and their use in robotics. The liquid-phase technologies for their production are the most competitive in the production of products from the NCAA on an industrial scale in order to reduce the cost of constructional parts of the mechanical robots.

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