MODERN METHODS OF METAL MATRIX COMPOSITE ALLOYS PRODUCTION AND NEW APPROACHES TO REALIZATION OF REINFORCING SCHEME

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Abstract: *In present work classification of known liquid-phase methods of manufacturing metal matrix composite alloys is offered. Methods of exogenous reinforcing provide input of prepared reinforcing particles in matrix melt. Methods of endogenous reinforcing provide formation of endogenous reinforcing phases directly in the melt due to flowing of controlled exothermic reactions between components of initial composite mixes. Distinctive features of interaction of phases at flowing of processes of liquid-phase high-temperature synthesis provide opportunity for realization of new conceptual approaches to realization of scheme of the reinforcing, based on combination of endogenous and exogenous reinforcing of a matrix alloy with particles of various nature and sizes.*

KEYWORDS: *METAL MATRIX COMPOSITE ALLOYS, LIQUID-PHASE TECHNOLOGY, EXOGENOUS AND ENDOGENOUS REINFORCING*

1. Introduction

Effective development of modern engineering is impossible without creation and implementation of new advanced materials corresponding to constantly increasing requirements and capable to successful work in hard operation conditions. Traditional alloys don't have all characteristics which are required for modern growth of industry production; therefore one of the most perspective ways in this direction is development of metal matrix composite alloys (MMC's). Application of MMC's allows reaching of significantly increasing of mechanical and operational properties of products [1].

Composite alloys are a special class of heterophase materials for functional and structural purposes, consisting of a metal base (matrix) reinforced with uniformly distributed high-melting and high-modulus particles of exogenous or endogenous nature, which aren't dissolving in matrix metal at temperatures of manufacturing and exploitation. These materials differ from conventional alloys by increased values of physic-mechanical and operational properties, including high specific strength, damping capacity, heat resistance, wear resistance in the conditions of dry and abrasive wear in wider temperature and power interval of operation.

Currently as matrices for producing of MMC's using aluminum, magnesium, zinc, copper, titanium and their alloys [2]. Disperse particles of oxides, carbides, nitrides, borides, intermetallics and other high-melting compounds are used as a reinforcing phases.

2. Modern methods of MMC's production

At present time the development of technological processes of MMC's production has received considerable attention. Searches of effective technologies of composites production are important for expansion of a range and volumes of their perspective applications because areas for their use potentially exist in every industry where the increased performance characteristics are critical. Active researches in this area carried out by scientific groups and organizations in practically all countries with developed industry and high innovative activity, including USA, Germany, Japan, China, India, Russia, etc. [3].

The first works aimed at production of cast MMC's began in the mid-sixties of the XX century and were executed by Prof. P. Pohatgi in Suffern, New York (USA) [4]. Early experiments in this area were focused on the creation of composites of systems Al-graphite, Al-SiC and Al_2O_3 by mechanical stirring of reinforcing particles in matrix aluminum melt. Subsequently this method of MMC's production has been adopted by many foreign companies, and repeatedly improved and modified. American company Alcan Aluminium Ltd. one of the first started developments of MMC's manufacturing in industrial scale. Examples of production are composites based on aluminum matrix reinforced with SiC particles with sizes of 3..40 microns. Pioneers in industrial development of aluminum matrix composites are also known companies Duralcan and Alcoa.

Currently the most intensively studied and applied in industry methods of MMC's production are liquid phase methods based on the input of reinforcing particles in the matrix melt (exogenous reinforcing methods) or on formation of endogenous reinforcing phases directly in the melt due to flowing of controlled exothermic reactions between reactionary active components of initial composite mixes (endogenous reinforcing methods). The main problem in case of liquid-phase consolidation of matrix alloy with reinforcement is problem of physical and chemical compatibility of matrix and reinforcing phase with optimal level of interphase interaction. A crucial role is played by the phenomenon of high-temperature wettability, adhesion and contact interaction, defining behavior of interphase boundaries and strength of adhesive contacts in manufactured products, and as a result the quality and operational properties of composite alloys [7].

For producing of castings from MMC's uses such methods of casting as gravity-die casting, pressure-die casting, liquid metal forging and centrifugal casting. Technologies of gravitational moulding are usually used for composites containing less than 15 vol.% of dispersed phase. Since MMC's have higher viscosity in comparison with traditional alloys, in many cases it is preferable using of forced moulding. It should also be noted that application of pressure at producing of composite alloy castings allows to practically eliminating of porosity which inevitably arises at producing of MMC's by exogenous reinforcing methods.

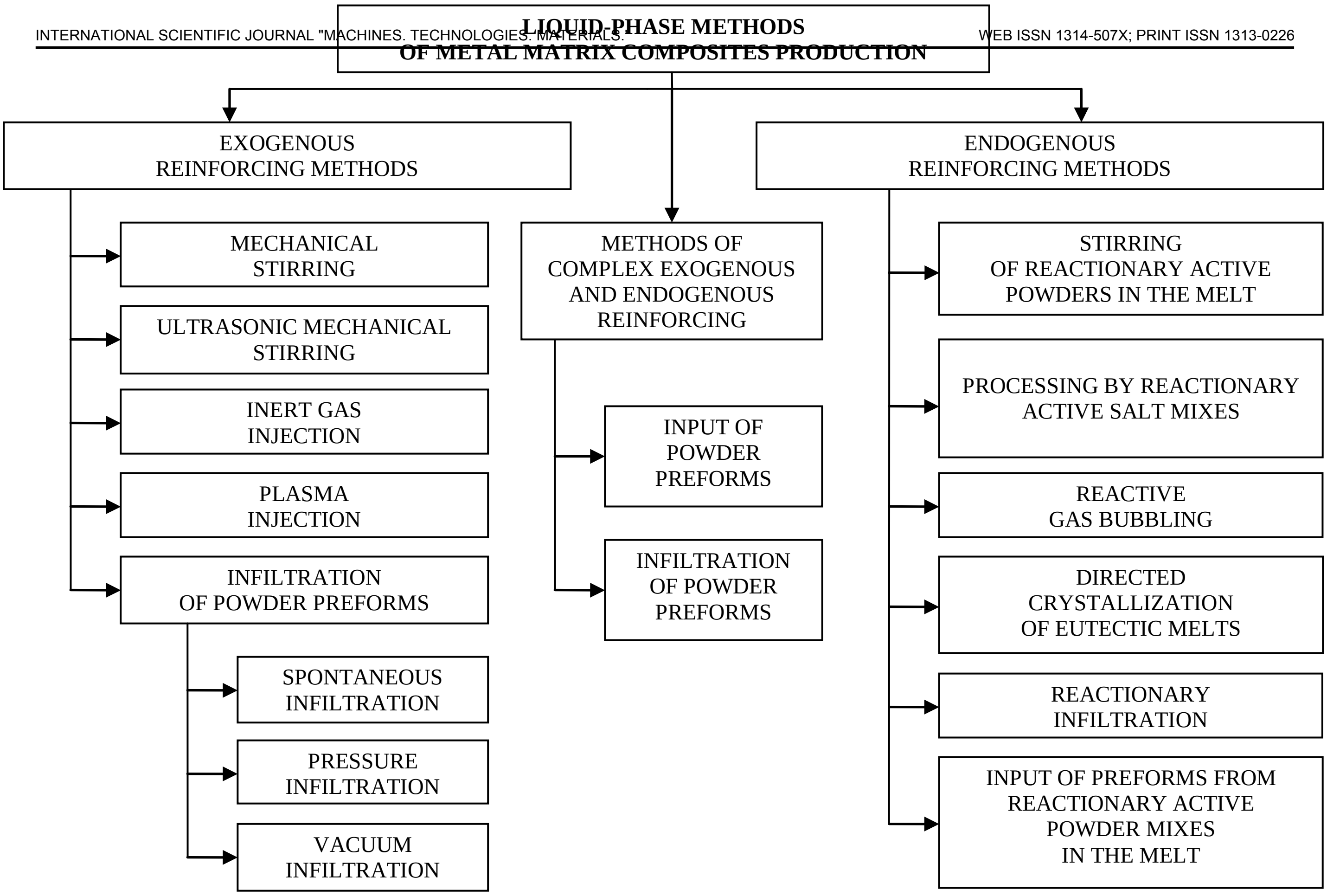

Fig. 1*. Classification of liquid-phase methods of MMC's production*

2.1. Exogenous reinforcing methods

Methods of exogenous reinforcing (Fig. 1) provide input of prepared reinforcing particles in matrix melt and include mechanical stirring, ultrasonic stirring, inert gas injection, plasma injection and infiltration of powder preforms. Method of mechanical stirring of discrete high-melting particles in liquid metal is now the most widely used due to its simplicity and universality. Units for this process include the crucible with the matrix melt, set in the oven, and a mechanical activator for melt mixing. Reinforcing particles are introduced by backfilling on rotating impeller blades. After preparing the slurry it is poured into the mold [8]. Stirring of composite alloy for uniform distribution of particles can be carried out not only by the impeller, but also by means of exposure of ultrasound on the melt [9]. In [10] noted that in the ultrasound field observed wetting of ceramic particles not-wettable under normal conditions.

There are various modifications of this method: mechanical stirring of insoluble particles in the melt by using of a gas or plasma jet using the plasma torch injection [11, 12]. However, the mechanical stirring method has some significant drawbacks: oxidation and gassing of matrix alloy during active mixing (as a consequence, increased porosity of composite castings), coagulation of reinforcement, low adhesive bond at the interface between the matrix and reinforcement, the need for special equipment. From the viewpoint of thermodynamics composite alloys obtained by this method are far from equilibrium, in which may be intense reactions between the reinforcing components and the matrix alloy, leading to degradation of the reinforcing phase and to formation of undesired products of such interaction. Furthermore, it is difficult to ensure continuous and full contact of matrix and reinforcing phase, the optimal level of interfacial interaction, which is often caused to poor mechanical and operational properties of the material.

2.2. Endogenous reinforcing methods

Other direction in manufacturing of composite alloys are methods of liquid-phase reactionary synthesis (in-situ-process) when new endogenous reinforcing phases formed as a result of controlled exothermic reactions between initial components directly at the stage of alloys production or at during subsequent thermal or thermomechanical processing, providing reinforcing through the precipitation (crystallization) of new phases from the amorphous state or a supersaturated solid solutions. The composites obtained in such processes have a maximum level at the interface boundaries due to small lattice mismatch of the contacting phases, thermal stability, better distribution and dispersion of reinforcement, which ultimately provides a high mechanical and performance properties. Size of the new phases can be adjusted by selecting of the combination of components participating in the in-situ-reactions, and also their form and volume content. It is no need for special equipment, which greatly simplifies and reduces the cost of technology of MMC's production [13].

Liquid-phase reactionary synthesis can be carried out by the following ways:

- mechanical stirring of reactionary active powders, interacting with the matrix melt to form a new reinforcing phases;
- infiltration of preform (preheated and placed in a crucible) by matrix melt;
- bubbling of matrix melt by active gas;
- mixing in the melt of salt mixes containing a reactionary active components;
- directed crystallization of eutectic melts;
- input of preforms containing reactionary active components in the matrix melt.

Considerable practical interest is represented by technology of MMC's production in which reinforcing of a matrix is carried out due to input of the preforms consisting of reinforcing components. This technology allows excluding the active mechanical stirring of the melt, thereby reducing its gas-saturation and oxidation. In addition, this technology allows to enter into a matrix high-dispersible (including nanosized) reinforcing components which can't be entered by mechanical stirring.

2.3. New approaches to realization of reinforcing scheme

Distinctive features of interaction of phases at flowing of processes of liquid-phase high-temperature synthesis provide opportunity for realization of new conceptual approaches to realization of scheme of the reinforcing, based on combination of endogenous and exogenous reinforcing of a matrix alloy with particles of various nature and sizes. The composites produced in these processes have two levels of reinforcing of a matrix, i.e. contain the endogenous reinforcing phases which are forming at flowing of in-situ reactions in matrix melt, and exogenous reinforcing phases, conditions for wetting and assimilation of which are created at flowing of exothermic reactions of synthesis of endogenous phases.

According to the offered scheme of reinforcing compositions and technology of production of complex reinforced aluminum matrix composite alloys of system [Al]-TiO_2-B(C)-Ti-SiC are developed. The liquid-phase technology of complex-reinforced MMC's production is based on input in a matrix melt of the pressed preforms consisting of reactionary active components [14]. For formation in volume of a matrix alloy of endogenous phases as the initial components powders of aluminum, dioxide of titanium, the amorphous boron, graphitized cocsic and titanium as in case of their interaction with each other and with a matrix aluminum melt pass the intensive exothermic reactions leading to formation of the new endogenous reinforcing and modifying phases TiB_2, TiC, Al_2O_3, Al_3X, AlX, AlX_3 (where X – Ti, Zr, V, Fe, Ni) are used. Additional regulation of physic-mechanical and operational properties of a composite alloy over a wide range can be carried out by adding in composition of the initial powder preform of exogenous ceramic particles.

Conducted researches of properties and characteristics of new complex reinforced MMC's shows that the hardness of composite alloy increases by 35-40% at a normal temperature and to 30% at an increased temperature, the friction coefficient decreases by 5-7 times, and the wear resistance increases at 10-12 times in comparison with a matrix alloy [15].

Technology of production of developed complex-reinforced MMC's implemented at foundry plant "Litmash, LLC" (Shuya, Ivanovo region) at manufacturing of castings for tribotechnical purposes [16].

3. Conclusion

Complex approach to creation of MMC's based on reinforcing of a matrix alloy with endogenous and exogenetic phases of different nature and the sizes significantly expands opportunities for purposeful achievement and regulation of properties of composite alloys. The received results convincingly testify that developed MMC's can be offered as effective changeover of traditional alloys in high-loaded friction units of different technological equipment and transport.

4. Literature

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