THE IMPACT OF FREQUENCY COMPOSITION OF CONSOLIDATION CURRENT ON THE STRUCTURE AND PHYSICAL-MECHANICAL PROPERTIES OF Ti-Al-C SYSTEM METAL MATRIX COMPOSITES

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Abstract: *The impact of industrial frequency (50 Hz) current with the voltage of U = 10 V while using the Field Activated Pressure Assisted Synthesis (FAPAS) method as well as the impact of superposition of direct and alternating (with 10 kHz frequency) currents with the voltage of U = 2 V while using Spark Plasms Sintering (SPS) method on the phase composition, structure and properties of Ti-Al-C system metal-matrix composites, consolidated from the powder mixtures, prepared by high voltage electric discharge, is experimentally studied. It is shown, that using SPS and FAPAS methods allows synthesis of materials, dispersion-strengthened by phases of TiC and Al_4C_3 carbides and Ti_3AlC_2 MAX-phase. It is found out, that using FAPAS method allows obtainment of Ti-Al-C system composites with higher values of density, hardness and wear-resistance, than those of materials obtained by SPS due to more homogeneous structure. Such a differences can be explained by the fact that high frequency (10 kHz) current component promotes movement of disperse phase inside the matrix, which leads to the agglomeration of strengthening particles as well as to increase of obtained composite porosity up to ~ 8 %.*

Keywords: metal-matrix composite, MAX-phases, high voltage electric discharge, synthesis, spark plasma sintering.

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1. Introduction

Metal-matrix composite materials (MMC) are such materials, in which matrix consists of metal or metal alloy. Ultrafine powder particles or fiber materials of different origins in most cases are acting as a reinforcing components.

MMC's are characterized by a combination of high physical and mechanical properties that are inherent to metals (plasticity and viscosity) and those that are inherent to ceramics (high strength and high elastic modulus) [1, 2]. During the recent years, the interest to metal-matrix composites from the companies of aerospace, automotive, machine building and other industries increases steadily.

Usage of relatively low-cost reinforcing components and development of different technological approaches can lead to less costly and simpler technology of MMC's production [3]. Thus the development of new physical principles of such materials production is an urgent task for scientists and engineers. Methods of high energy preparation of powders and their consolidation by passage of electric current are actively developing nowadays. This allows obtainment of materials with higher values of physical and mechanical properties than those of materials obtained by conventional metallurgy methods.

2. Problem discussion

The universal complex for electric sintering of powder materials, which can use two different current sources of power up to 10 kW, was created at the Institute of Pulse Processes and Technologies of NAS of Ukraine [4]. First electric current source for this complex is based on the superposition of direct and alternating (with frequency of 10 kHz) currents at the working voltage of U = 2 V (this source allows realization of Spark Plasms Sintering (SPS) method), and the second source is based on alternating current with industrial frequency of 50 Hz at the voltage of U = 10 V and allows realization of Field Activated Pressure Assisted Synthesis (FAPAS) method.

The possibility of creation of metal-matrix composites of Ti-Al-C, reinforced with MAX-phases, by preliminary treatment of powder material with high voltage electric discharge (HVED) and subsequent high-frequency low-voltage sintering by SPS method was shown in work [5]. According to [6], thee composites can compete on the market with industrial alloys, based on Ti_3Al (α-2, 57 % Ti + 25 % Al + 17 % Nb + 1 % Mo) and TiAl (γ, 50.8 % Ti + 45 % Al + 1 % Nb + 2.5 % Cr + 0.2 % B + 0.5 % Ta) intermetallic compounds.

Thus the studies of impact of frequency current composition during the consolidation of powder mixtures with SPS and FAPAS methods on the physical and mechanical properties of obtained materials are of high scientific urgency.

The goal of present work is the studies of impact of frequency current composition during the consolidation on the physical and mechanical properties of Ti-Al-C system materials specimens.

3. Objective and research methodologies

The approach, in which synthesis of reinforcing components occurs in two stages, was used for obtainment of Ti-Al-C system metal-matrix composites. On the first stage (powders preparation) dispersion and surface preparation of powders as well as the synthesis of dispersion-strengthening inclusions takes place. On the second stage (consolidation) synthesis of materials with dispersion-strengthening additives with the preservation of nanostructure occurs.

High voltage electric discharge treatment of powders of 85 % Ti + 15 % Al initial composition in hydrocarbon liquid was used on the first stage [7].

4. Results and discussion

Obtained powders were studied with "Biolam-I" («Биолам-И») optic microscope using Image-J software according to [8]. As a result, histograms of particles distribution by their size and form factor (see Fig. 1 and Fig. 2) were obtained. It is found out that more than 70 % of particles have size less than 10 µm, while 35 % of particles have size of ~ 3 µm and 5 % of particles have size of ~ 0.6 µm. The predominant forms of particles are spongy (35 %) and spherical (30 %). Mean diameter of particles in initial powder mixture was 30-50 µm. Most particles of initial powder mixture had spongy form.

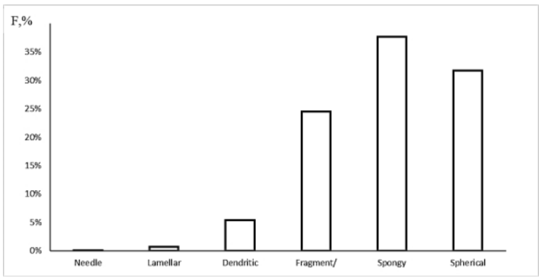


Fig. 1 *– Distribution of particles of powder mixture of Ti-Al-C system after HVED treatment by their form*

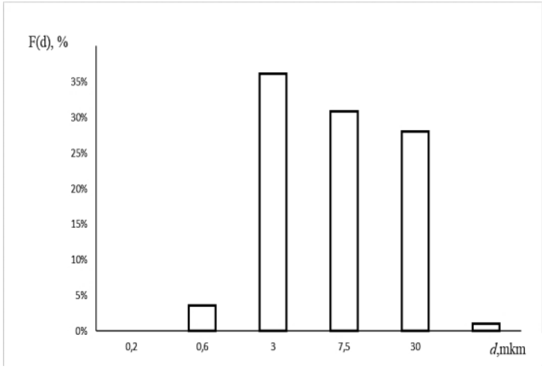


Fig. 2 *– Distribution of particles of powder mixture of Ti-Al-C system after HVED treatment by their diameter*

The usage of hydrocarbon liquid (kerosene) as a working medium during HVED treatment of initial Ti-Al-C system powder mixture allows excluding the introduction of additional carbon during powders preparation [5].

According to results of X-ray diffraction analysis of Ti – Al powder system after HVED treatment (X-ray diffraction patterns were obtained on Rigaku Ultima IV X-ray diffractometer), content of Titanium carbide in obtained powder mixture is ~ 25 % (see Fig. 3).

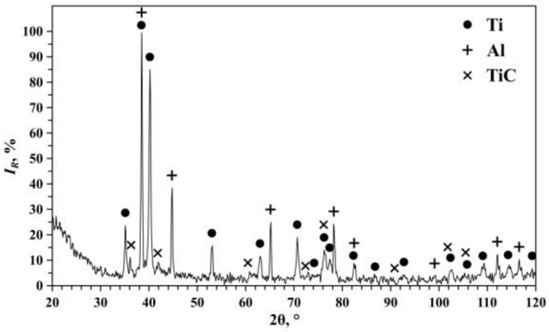


Fig. 3 *– X-ray diffraction pattern of powder mixture of Ti-Al-C system after HVED treatment*

The impact of current of different frequency composition on the properties of consolidated cylindrical specimens with diameter of 10 mm was studied by comparison of physical and mechanical properties of composites that were obtained from powder mixture of Ti-Al-C system, synthesized by HVED, that was consolidated using SPS and FAPAS methods. Consolidation by both methods was performed under pressure of 60 MPa in vacuum with isothermal holding at 1100 °C during 300 s.

Physical, mechanical and performance properties of obtained materials, such as density, wear resistance, Vickers hardness and dynamic strength, were studied.

Studies of abrasive wear resistance were performed on SMC-2 (СМЦ-2) friction machine using "roller – block" scheme [9]. Pair of friction consisted of immovable cylindrical specimen (d = 10 mm, h = 6 mm) of studied material (block) and roller (counter-body) made from quenched and tempered 1045 steel (Сталь 45). Friction conditions: no lubricant, peripheral speed – 0.785 m/s, specific pressure – 0.75 MPa, distance – 5 km.

Roller was rotated by machine operating axis with frequency of 300 spins/min. Specific load on the block was 60 kg/cm^2. Studies were preceded by the preparation of contact surfaces that was performed by fitting with pre-friction during $30 \cdot 10^3$ work cycles.

During the studies, control of the load on the block and the way, which the specimen has passed, was performed. control of the wear was performed by the determination of specimens mass (using "Tehnovagy-TVE-0.21" («Техноваги-ТВЕ-0.21») lab scales of 2 accuracy class after each 0.5 km of the way. Dynamic compressive strength was studied using specimens compression diagrams, obtained on split Hopkinson (Kolsky) bar experimental stand for dynamic studies [10]. Values of ultimate dynamic compressive strength and deformation energy during the destruction were determined using the obtained data.

X-ray diffraction analysis of consolidated specimens have shown that after consolidation of powder mixtures, prepared by HVED, using SPS (see Fig. 4) and FAPAS (see Fig. 5) methods the intensity of TiC peaks have increased, which indicates the significant increase of this phase concentration.

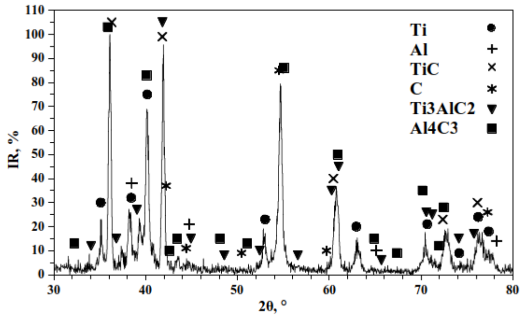


Fig. 4 *– X-ray diffraction pattern of specimens, consolidated using SPS method*

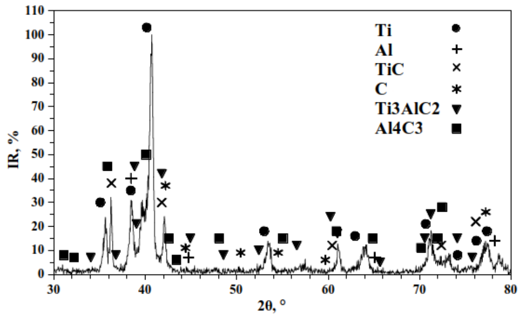


Fig. 5 *– X-ray diffraction pattern of specimens, consolidated using FAPAS mehod*

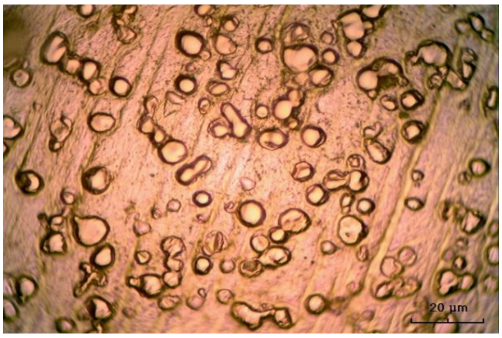
The intensity of Ti and Al peaks have notably decreased. Also, synthesis of such dispersion-strengthening phases, as TiC, Al_4C_3 and Ti_3AlC_2 MAX-phase takes place. It should be noted that intensity of dispersion-strengthening phases peaks is higher in case of using SPS than in case of using FAPAS method, which indicates that SPS ensures higher efficiency of their synthesis.

Properties of composite materials, based on Ti-Al-C system, obtained using SPS and FAPAS method are given in Table 1.

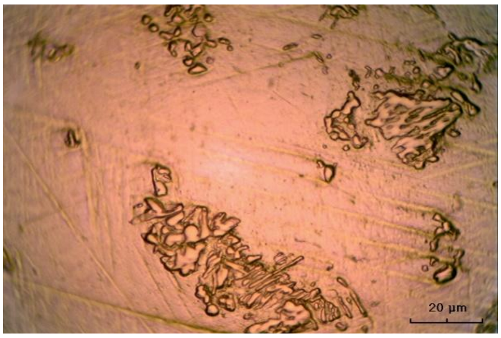
Table 1 *– Properties of specimens, obtained by FAPAS and SPS methods*

Sintering method	Porosity, %	Hardness HV, GPa	Dynamic strength, MPa	Loss of mass during abrasive wear, %
FAPAS	1	6.7	970	0.7
SPS	8	5	490	1.8

As it can be seen from this table, physical and mechanical properties of composite materials, obtained using FAPAS method, are significantly higher than those of composite materials, obtained using SPS method. Such significant difference of their characteristics can be explained by the fact that high-frequency component of current (frequency of 10 kHz) promotes movement of disperse phase inside the matrix, which leads to the agglomeration of strengthening particles (see Fig. 6, b) as well as to increase of obtained composite porosity up to ~ 8 %. sintering with the industrial frequency current allows obtainment of the material with homogeneously distributed structure (see Fig. 6, a) and porosity of ~ 1 % and less.



a



b

Fig. 6 *– Optic microphotographs (×1000) of consolidated specimens of HVED-treated powders of initial 15 % Al + 85 % Ti composition, obtained using FAPAS (A) and SPS (b) methods*

Characteristic diagrams of stress, strain rate and strain energy density of the specimen, made by FAPAS of powder mixture of Al – Ti after HVED treatment, are shown on Fig. 7. According to the curve 1 of Fig. 7, dynamic stress in the specimen σ^{cs} was around 970 MPa, while strain rate υ^{d} was around 580 s^{-1} (see Fig. 7, curve 2) and energy density E_d was 10 MJ/cm^3. Loss of mass during abrasive of this specimen was ~ 0.7 % after way of 5 km.

It is clear that the use of electric current of different frequency composition for consolidation of powder mixtures allows influencing the processes of liquid metal transfer and diffusion as wells as the size of strengthening phase in obtained specimens.

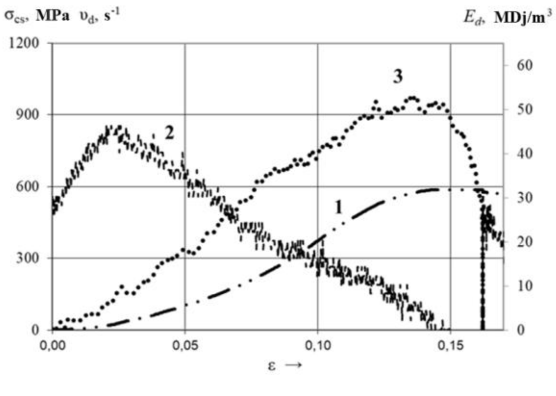


Fig. 7 *– Diagram of compressive stress (1), strain rate (2) and strain energy density (3) of the specimen, obtained using FAPAS method*

5. Conclusions

1. It is found out, that the use of currents of different frequency composition (superposition of direct current and alternating current with 10 kHz frequency or alternating current with industrial frequency of 50 Hz) during the consolidation of Ti – Al – C powder mixture can influence the processes of liquid metal transfer and diffusion as wells as the size of strengthening phase in obtained specimens, which impact physical and mechanical properties of obtained specimens.

2. It is shown, that the use of SPS and FAPAS methods allows synthesizing of the materials, dispersion-strengthened by TiC abd Al_4C_3 carbides and Ti_3AlC_2 MAX-phase. Intensity of dispersion-strengthening phases on the X-ray diffractograms is higher in case of using SPS method, yet their agglomeration is observed.

3. It is found out, that the use of FAPAS method allows obtainment of Ti – Al – C system MMC's with higher values of hardness and wear resistance, than of those obtained using SPS method. This is due to the formation of more homogeneous structure.

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