THE IMPACT OF ELECTRIC FIELD DISTRIBUTION DURING Ti – Al – C SYSTEM BLEND PREPARATION ON PHYSICAL-MECHANICAL PROPERTIES OF CONSOLIDATED MATERIALS

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Abstract: The possibility of control of efficiency of different factors of high voltage electric discharge (HVED) impact on Ti – Al – C powders system for aimed synthesis of dispersion-hardening components is shown. Nanolamine-composite Ti₅AlC₂ – TiC with hardness of HV₅ = 7 GPa, obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED with the use of multi-point electrode system has needle structure of Ti₅AlC₂ (a = 0.3068 nm, c = 1.844 nm) with size up to 10 µm, and TiC dispersion-hardening phase (a = c = 4.4331 nm) with particle size no more than 1 µm is situated between grains of Ti₅AlC₂. Dynamic strength of specimens depending on electrode system used during HVED treatment of blend varied in range from 160 to 620 MPa, Young modulus – from 13 to 22 GPa at deformation rate from 600 to 900 s⁻¹. Material has high levels of heat resistance, relative change of mass is no more, than 0.001.

KEYWORDS: ELECTROMAGNETIC FIELD, METAL-MATRIX COMPOSITE, POWDER MATERIAL, DISPERSE FILLER, HIGH VOLTAGE ELECTRIC DISCHARGE, POWDER METALLURGY, BLEND PREPARATION, ALUMINUM MATRIX COMPOSITES, PHASE COMPOSITION, SYNTHESIS, DISPERSION, MAX-PHASE

1. Introduction

Efficiency of the usage of high voltage electric discharge (HVED) for preparation of homogeneous highly disperse blend for production of metal-matrix composites (MMC) of different compositions was shown earlier in papers [1, 2]. The possibility of control of efficiency of different HVED impact factors for aimed synthesis of dispersion-hardening fillers was shown in work [2]. HVED treatment combines even distribution of interparticle discharges plasma and hydrodynamic impact, which intensifies processes of structure and phase formation.

It is shown in paper [3], that control of volumetric distribution of interparticle discharges plasma in powder is possible by control of electromagnetic field (EMF) by variation of electrode system construction, which can impact processes of structure and phase formation in treated blend.

The goal of present work is to study the impact of electrode system configuration on the distribution of plasma formations in “kerosene – powder” disperse system and on the properties of obtained blend and consolidated materials.

2. Preconditions and means for resolving the problem

Mixture of metal powders of PA-4 (ГОСТ 6058-73 (IIA-4 ГОСТ 6058-73) Aluminum powder (mean diameter 23 µm) and TU U14-10-026-98 (ТУ 14-10-026-98) Titanium powder (mean diameter 63 µm) of 15 % Al: 85 % Ti mass relation was used as initial material.

HVED treatment was performed at experimental stand, which is described in detail in work [2]. Powder mixture was loaded into discharge chamber, then TS-1, ГОСТ 11128-65 (ТС-1, ГОСТ 11128-65) kerosene was added (relation of disperse and continuous phases was 1:10 [4]). Specific treatment energy was 25 MJ/kg, which allowed synthesis of necessary for dispersion-hardening components synthesis quantity of nanocarbon as a result of hydrocarbon destruction under the impact of discharge channel plasma [4].

Consolidation of powder materials was performed at spark-plasma sintering (SPS) device [5] in vacuum by passage of superposition of direct and pulsating currents with 10 kHz frequency at working voltage of 2 V. Powder was poured into MPG-6 (МПГ-6) graphite matrixes with inner diameter of 10 mm, pressure of blend pre-pressing was ~ 30 MPa and sintering pressure was ~ 60 MPa in all considered experiments. Measurement of specimens temperature during sintering was performed by standard K-type thermal couple. Al – Ti – C system specimens isothermal holding temperature was 1100 °С according to MAX-phases formation zones [6]. Specimens heating rate during consolidation was selected according to works [7, 8] and was 10 °С/s. According to work [9], it was determined that isothermal holding time has to be no more, than 3 min, in order to preserve ultrafine nanostructured phases during consolidation.

BIOLAM-4 (BIOLAM-H) optical microscope with maximal magnification of × 1350 and REMMA-102 (PEMMA-102) raster electron microscope with magnifications range from ×10 to ×250000 were used for analysis of powder particles morphology.

Studies of phase composition and crystal structure were performed by X-ray diffraction analysis using Rigaku Ultima IV X-ray diffraction meter (CuKα radiation). Vickers hardness was determined using IT 5010 (HT 5010) hardness meter.

Dynamic compression strength of specimens was studied using their compression diagrams, obtained by using experimental device for dynamic tests by Hopkinson-Kolsky method [10].

3. Results and discussion

Three types of electrode system (ES) construction were used during powders HVED treatment: “point – plane” (P – P), No. 1 (See Fig. 1, a) and two variants of “multipoint anode – plane” ES (МP – P), No. 2 and No. 3 ((See Fig. 1, b and с correspondingly).

It is worth noting, that cyclic formation gas-vapor cavity only in near-electrode zone while using ES No. 1 (see Fig. 1, a) leads to ejection of powder from chamber central part and leads to amplification of hydrodynamic impact. Yet, amplification od hydrodynamic impact leads to weakening of erosion (ablation) of particles due to decrease of solid phase concentration in chamber central part.

The picture of plasma formations distribution caused by No. 2 ES construction (see Fig. 1, b) is not qualitatively different from distribution, caused by No. 3 ES construction (see Fig. 1, c) – in both cases interparticle discharges plasma is almost evenly distributed in powder volume.
Due to cone shape of No. 3 ES, which follows the shape of chamber bottom, volumetric distribution of plasma formations is more even if compared to No. 2 ES.

The possibility of control of efficiency of different HVED factors impact on Ti–Al system for aimed synthesis of dispersion-hardening components (TiC titanium carbide, AlTi3, AlTi, Al2Ti, Al3Ti, Ti3AlC and Ti3AlC MAX-phases and Lonsdaleite) by changing electric field configuration by using different types of ES was shown earlier in works [11, 12]. It was experimentally found out, that HVED treatment of Ti–Al powder systems (75 % Ti + 25 % Al, 50 % Ti + 50 % Al and 25 % Ti + 75 % Al) in kerosene leads to their dispersion, main peak of their size distribution moves to point of ~ 3 µm, and no less than 20 % of particles have size less than 1 µm.

As a result of HVED treatment of powder mixture of 85 % Ti + 15 % Al composition, considered in present work, particles mean diameter decreased ~ 4.5 times in case of ES No. 1 usage, and while using ES No. 2 and No. 3 dispersion efficiency decreases ~ 3 times. Change of phase composition also occurs TiC dispersion-hardening component is synthesized (a = c = 4.329 ± 0.003 nm), intensity of its synthesis increases when using ES No. 2 and No. 3.

From practical point of view, it is important to study the impact of powder blend characteristics change due to the use of different ES types on consolidated materials properties.

SPS consolidation of blend, obtained while using ES No. 1, led to phase transformations in consolidated material – formation of TiC (a = c = 0.86413 ± 0.0015 nm) and Al3Ti (a = 0.38512 ± 0.0019 nm, c = 0.8607 ± 0.0004 nm) with the release of free Carbon (see Fig. 2). Large quantity of Carbon impacted the structure and hardness of obtained material. Carbon is uniformly distributed by specimen volume (see Fig. 2), creating dark zones with microhardness of 0.7 GPa and light zones with microhardness of 1.3 GPa. Vickers hardness of specimens was 0.9 GPa.

As a result of HVED treatment with the use of ES No. 2 and subsequent consolidation, formation of Ti3AlC2 (a = c = 0.390 ± 0.003 nm) and Al4C3 (a = 0.33357 ± 0.00006 nm, c = 2.5288 ± 0.0004 nm) occurs, as well as absorption of Aluminum (see Fig. 3). This leads to formation of light zones with microhardness up to 11 GPa and gray zones of hardened Titanium with microhardness up to 8 GPa (see Fig. 3). Vickers hardness of obtained material was 5.28 GPa.

![Fig. 2. Phase composition and structure (magnification ×250) of MMC, obtained from powder of 85 % Ti + 15 % Al initial composition after HVED treatment with the use of ES No. 1](image-url)
Metal-matrix composite, obtained from blend, prepared by HVED with the use of ES No. 3 consists of Ti₃AlC₂ \((a = c = 0.4131 \pm 0.0007 \text{ nm})\) and Al₄C₃ \((a = 0.3344 \pm 0.0004 \text{ nm}, \ c = 2.509 \pm 0.003 \text{ nm})\) phases (see Fig. 4). Light zones with microhardness up to 13.8 GPa and gray zones of hardened Titanium with microhardness up to 7 GPa are formed in specimen structure (see Fig. 4). Vickers hardness of obtained nanolaminate-composite Ti₃AlC₂ – TiC with homogeneous fine grain structure is 7 GPa.

Materials, obtained from powder of 85 % Ti + 15 % Al initial composition after HVED treatment with the use of ES No. 3 have the highest hardness \((HV_5 = 7 \text{ GPa})\) among considered specimens (see Fig. 5).

Dynamic strength of specimens, obtained from blend after HVED treatment, depending on used ES type, varied in range from 280 MPa to 600 MPa (see Fig. 6), and Young modulus varied in range from 13 GPa to 22 GPa at deformation rated from \(600 \text{ s}^{-1}\) to \(900 \text{ s}^{-1}\) (see Fig. 7).

Results of heat resistance studies show, that unbound Carbon has negative impact on heat resistance of composite, consolidated from blend after HVED treatment with ES No. 1. Relative mass change for such specimens was 0.09. Nanolaminate-composite Ti₃AlC₂ – TiC, obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED treatment with ES No. 2 and No. 3, contrary to case of ES No. 1, have high values of heat resistance (see Fig. 8).
4. Conclusions

1. It is found out, that control of efficiency of different HVED impact factors for aimed synthesis of dispersion-hardening components is possible by changing EMF configuration due to use of different ES types.

2. Nanolaminate-composite Ti₃AlC₂ – TiC with hardness of HV = 7 GPa) obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED treatment with ES No. 3, has needle structure of Ti₃AlC₂ (a = 0.3065 nm, c = 1.844 nm) with size up to 10 µm, and TiC dispersion-hardening phase (a = c = 4.4331 nm) with particle size no more than 1 µm is situated between grains of Ti₃AlC₂.

3. Dynamic strength of specimens, obtained from blend after HVED treatment, depending on used ES type, varied in range from 280 MPa to 600 MPa, and Young modulus varied in range from 13 GPa to 22 GPa at deformation rated from 600 s⁻¹ to 900 s⁻¹.

4. Nanolaminate-composite Ti₃AlC₂ – TiC, obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED treatment with ES No. 2 and No. 3, contrary to case of ES No. 1, have high values of heat resistance due to formation of fine grain hardened Ti₃AlC₂ – TiC structure – relative mass change is 0.001.

5. Literature


