SHOCK-WAVE SYNTHESIS AND PROPERTIES OF MMC REINFORCED WITH Al_2O_3, AlN AND AlB_2 (NANO) PARTICLES

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Abstract

In this paper the method of shock-wave compaction was used for synthesis of metal matrix composites (MMC). For the experiments were selected following compositions of the composites: Al-10 wt.% of Al_2O_3 nanoparticles and Al-10 wt.% of AlN, AlB_2 microparticles. Base of the matrix material was selected a fine powder of aluminum with a particle size of 20 microns. Powder mixtures of given composition were placed in aluminum tubes 400 mm long and 10 mm in diameter, sealed hermetically, and then carried out their detonation. As the explosive TNT used. It was found that the method of shock-wave compaction produces metal matrix composites with a density close to the theoretical density of aluminum. We also studied the microstructure, phase composition, fine crystal structure parameters and mechanical properties of the MMC.

Introduction

In the recent years the use of aluminum based composites increasingly being considered for applications in the aerospace and automotive industries because they show exceptionally good strength to weight ratio [1, 2]. Traditionally used aluminum alloys currently reached the limit of their properties and new lightweight materials such as Al-based metal-matrix composites (MMC) and metal-matrix nanocomposites (MMNC) are under development [3]. Composite materials based on Al represent a metal matrix with specified distribution of reinforcing elements (particles, fibers etc.). Particulate reinforcement seems to be more universal than with fibers. The latter tend to form bundles and maybe more suitable for the preform route. Particle reinforcement blocks dislocation and grain boundary motion and effectively strengthens the material at room and elevated temperatures [3]. MMC and MMNC reinforced with particles exhibit high physical and mechanical properties (Young's modulus, ultimate tensile strength, yield strength, hardness, durability, specific electrical and thermal properties) [4, 5]. Micro- and nano-sized particles of oxides, carbides, nitrides, borides etc. can be used as reinforcing particles. MMC usually require a considerable loading of 5 to 20% with particles of up to 10 μm [3, 6].

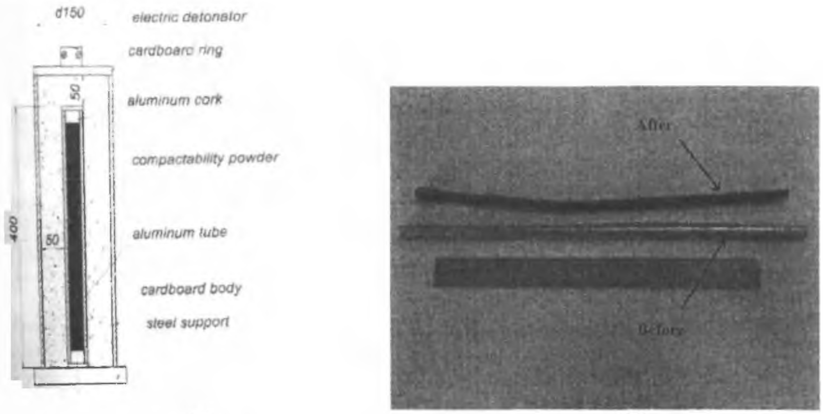
Nowadays, for MMC synthesis uses following technological routes: powder metallurgy. liquid-metal processing, preform impregnation etc. Particularly traditional metallurgical processes are associated with an increase of grain size, agglomeration nanoparticles and defect annealing, which require additional mechanical processing of the material, whereas preform-based routes are limited in size and shape of the manufactures parts. In this work for MMC synthesis we used powder metallurgy route, specifically shock-wave (SW) compaction [7-9] of powder mixtures Al-Al_2O_3, Al-AlN and Al-AlB_2 Shock-wave compaction of powder materials has been recently reviewed by Prummer [10] from its origins, which now spans more than four decades. Was shown that the method of dynamic powder compaction (SW-compaction) [10] enables manufacturing of a broad variety of solidity material with desired composition and density close to theoretical value; additionally this processing technique facilitates introduction of desired number of defects and reinforcement elements.

The objective of this work is to synthesis and study of properties of MMC produced by shock-wave compaction of aluminum powder mixed with Al_2O_3, AlN and AlB_2 (nano) particles.

Experimental

Fig. 1a shows the scheme for shock-wave compaction of an aluminum tube with powder mixtures. A 30-mm layer of TNT explosive (pad) compacted to ρ=1.25 g/cm^3 was poured into a cardboard cup (40 mm in diameter). A tube was positioned onto the pad using a centering cardboard ring. The gap was also fitted with the compacted explosive. A mixtures of 10 wt% Al_2O_3 nanoparticles (<100 nm), AlN, AlB_2 (~10 μm) and 90 wt% Al powder (<20 μm) was prepared in a tumble mixer with steel mixing bodies. The mixture was then placed in a 10-mm diameter aluminum (99.7% Al) tube that was sealed from both sides with aluminum stoppers. The tube with powder mixture was centered by means of a second ring, and then compacted explosive was put into the cup 50 mm above the tube. A standard electric detonator was installed in the middle of this layer at the 20-mm depth. The total mass of explosive was 860 g. The assembly was put into the blast chamber on a metal plate, detonator was connected to initiation circuit, the chamber was closed and the assembly was detonated. The samples before and after SW-compaction are shown on the Fig. 1(b).

The starting powders and MMCs were characterized using a Philips SEM 515 scanning electron microscope (SEM) and JEM 2100 transmission electron microscope (TEM). The particle size for powders was calculated using Mastersizer 2000 particle size analyzer. Phase composition and structural parameters of the starting powders and obtained composite were studied using a diffractometer with Cu$K\alpha$ - radiation. Step-by-step collection of X-ray patterns was performed with 0.02-0.1° step in the range 20°<2θ<120°. Phase identification was performed by comparing experimental patterns with ASTM-data. The sizes of crystallites were determined by using small-angle peaks and microdistortion of crystal lattice $<\varepsilon^2>^{1/2}$ was calculated using widening of reflection at large diffraction angles [11]. The density of the MMC was determined by the Archimedes method. Microhardness was measured using Nano Indenter G200/XP tester with a load of 250 g. At least three samples were tested for each condition and the average data are reported.



(a) (b)

Figure 1. The scheme for explosion compaction of aluminum tube with powder mixtures (a) and samples before (bottom) and after SW-compaction (above) (b).

Results and discussion

A SEM image of the Al powder for MMC synthesis is shown in Fig. 2. As it can be seen, Al powder consists of particles with a regular spherical shape. The average particle size was 18 µm. The specific surface area of the powder was 0.7 m^2/g. An XRD analysis showed that the size of crystallites (coherent scattering region, i.e. defect-free area of the crystal) in Al powder was 110 nm with the crystal lattice parameter 0.40479 nm and the crystal lattice microdistortion $<\varepsilon^2>^{1/2}$ 2.9×10^{-3}.

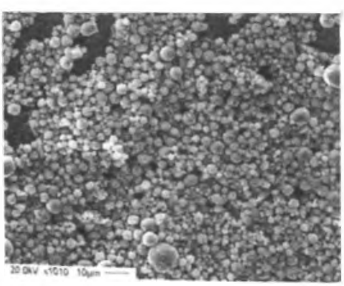
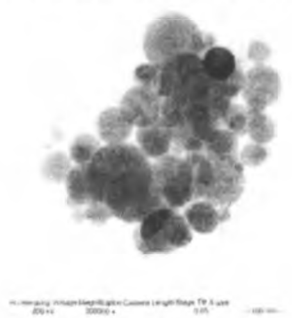
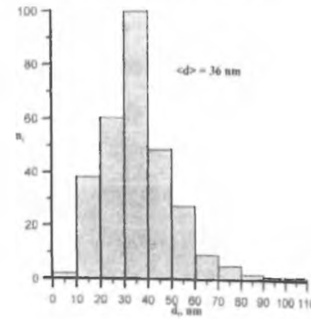


Figure 2. An SEM image of Al powder.

X-ray phase analysis shows that Al_2O_3 nanopowders (produced using EEW method [2], 12]) substantially consist of α and γ Al_2O_3 phase. The BET surface area is equal to 35-40 m^2/g. A typical image of particles in the powder is shown in Fig. 3 (a). As it can be seen the particles in the powder are separated even in agglomerates and have a regular spherical shape.



(a)

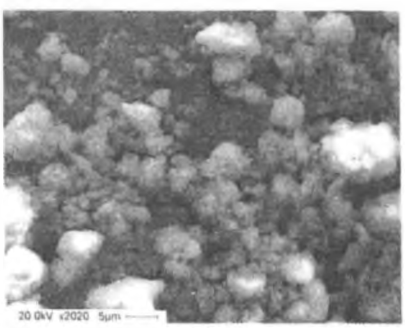


(b)

Figure 3. An TEM image of Al_2O_3 powder (a) and particle size distribution (b).

Particle size distribution bar chart is shown in Fig. 3 (b). Average particle size $\bar{a}_n$ = 36 nm; surface average size $\bar{a}_s$ = 45 nm; mass average size $\bar{a}_m$ = 54 nm.

An SEM images of the AlB_2 and AlN powders are shown in Fig. 4. As it can be seen, AlB_2 powder consists of particles with sharp edges with average size 5 μm, and AlN powder represents friable agglomerates consisting of irregularly shaped and spherical particles. The average size of spherical particles comprises 3 μm. The BET surface area of these powders is equal to 1 m^2/g.



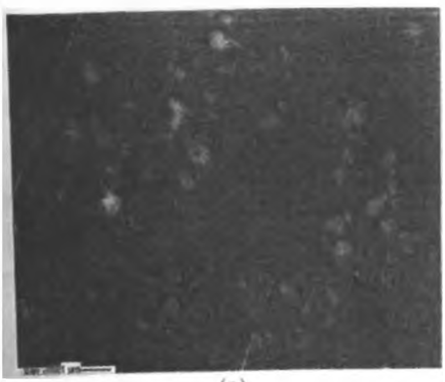
(a)

(b)

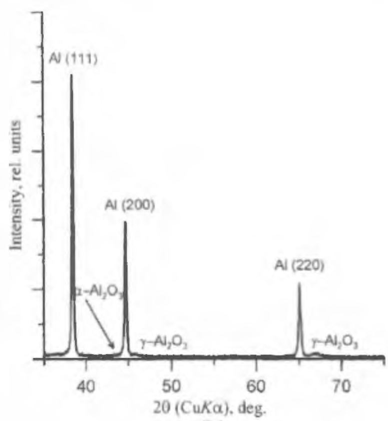
Figure 4. An SEM image of AlB_2 (a) and AlN (b) powders

The microstructure of an Al–Al_2O_3 MMC after shock-wave compaction is shown in Fig. 5 (a). The material has a fine grain structure and the grain size between 2 and 10 μm. It can be seen that in the structure of the material there are agglomerates of nanoparticles Al_2O_3. The size of these agglomerates up to 1 μm. Probably agglomerates can be formed in the material on the step of mix powders or nanoparticles can be sintered in agglomerates during the explosion.

The XRD-diagram of MMC sample (Fig. 5(b)) shows that there are two Al_2O_3-phases as apparent: α-Al_2O_3 (Corundum) and γ-Al_2O_3. A rough estimation of the main peak heights comparison gives a α/γ-ratio of approximately 30:70. The amount of aluminum oxide in composite is 9 %. It follows from ratio of reflection of phases Al and Al_2O_3 intensity. Data of microanalysis obtained with EDAX device of SEM confirms it - content of aluminum oxide in MMC is 8.7 %. An XRD analysis showed that the crystallites size in MMC Al–Al_2O_3 for aluminum phase was equal 65 nm with the crystal lattice parameter 0.4048 nm, and the crystal lattice microdistortion $<\varepsilon^2>^{1/2}$ 0.6×10^{-3}.



(a)



(b)

Figure 5. An SEM image of MMC Al-Al_2O_3 surface after shock-wave compaction (a) and fragment of the X-ray diffraction pattern of material sample

The microstructure of an Al–AlB_2 MMC after shock-wave compaction is shown in Fig. 6. It can be seen that the particle distribution is uniform in material structure. XRD analysis showed that the material contains aluminum phase and about 8.5% of the AlB_2 phase. An XRD analysis showed that the crystallites size in Al–AlB_2 MMC for aluminum phase was ≥ 400 nm with the crystal lattice parameter 0.4053 nm, i.e. above the table value for aluminum.

The microstructure of an Al–AlN MMC after shock-wave compaction is shown in Fig. 7. It can be seen that the particle distribution is irregular in material structure. On the Fig. 7 (a) shown the boundary between the matrix of MMC and aluminum tube.

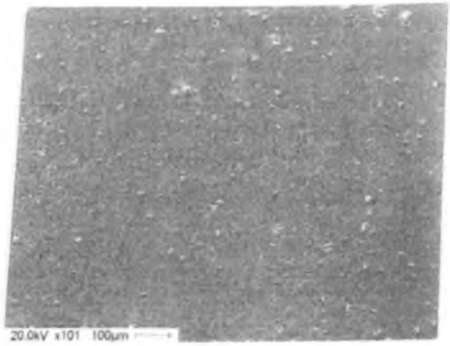


Figure 6. An SEM image of MMC Al-AlB_2 surface after shock-wave compaction

On the surface of this composite there are pores with the size up to 50 µm. XRD showed that the material contains aluminum phase and about 8% of the AlN phase. / analysis showed that the crystallites size in Al–AlN MMC for aluminum phase was 220 the crystal lattice parameter 0.4051 nm, i.e. also above the table value for aluminum as w the case of Al-AlB_2 MMC.

The density of all MMCs is close to the theoretical density of Al and ranges betw to 2.7 g/cm^3. Furthermore, the experiment is needed on the optimizing of technology fo synthesis in order to ensure uniform distribution of particles in the materials and to ac non-porous state.

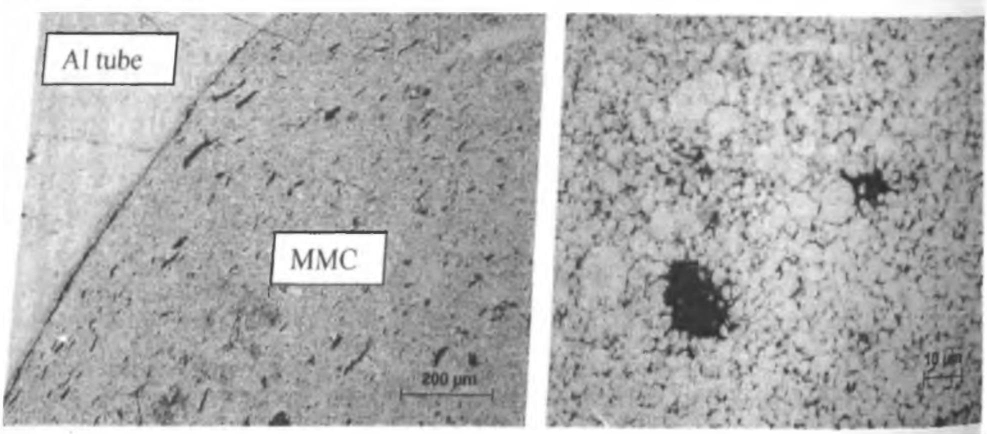


Figure 6. An optical image of MMC Al-AlB_2 surface after shock-wave compaction

The hardness measurements shown that maximum value (1050 MPa) has Al- MMC, whereas Al-AlB_2 and Al-AlN MMCs have a hardness value 720 and 700 respectively. The Young's modulus (defined indentation) for Al-Al_2O_3 and Al-AlB_2 equal GPa and for Al-AlN MMC Young's modulus equal about 100 GPa. Compressive strength fo Al_2O_3 MMC is equal 400 MPa.

Concluding remark

It was shown that shock-wave compaction can be used for synthesis of metal matrix composites Al-Al_2O_3, Al-AlB_2 and Al-AlN. The materials have a fine grain structure and the grain size between 2 and 10 μm. The nanoparticles Al_2O_3 after shock-wave compaction form agglomerates (with sizes up to 1 μm) in the MMC structure.

X-ray analysis showed that the aluminum crystallites in materials are ultrafine and equal 65-400 nm depending on the type of MMC.

The highest value of hardness (1050 MPa) has a Al-Al_2O_3 MMC. The density of all MMCs is ranges between 2.5 to 2.7 g/cm^3. Furthermore, the experiment is needed on the optimizing of technology for MMC synthesis in order to ensure uniform distribution of particles in the materials and to achieve a non-porous state.

Acknowledgement

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