

Cermet composite material based on aluminothermy

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Abstract

A new method for synthesis of cermet composite materials was developed based on aluminothermy. Employing this method a cermet composite material with a high content of AlN crystal phase was synthesized. Fine powders of aluminum and silica glass were mixed and heated in a corundum crucible for 6 hours at 1100°C in air. The X-ray diffraction analysis showed that the composite material thus synthesized contains a high concentration of AlN particles (about 33 vol. %) embedded in an aluminum silicon alloy. A small amount of Al₂O₃ particles (about 8 vol. %) was also found.

The method proposed can also be used for synthesis of aluminum matrix composite materials containing, besides AlN, other ceramic reinforcement phases. The properties of these composite materials can be tailored by choosing an appropriate composition of the initial powder mixture for aluminothermic synthesis.

Keywords: aluminum matrix composite, aluminum nitride, aluminothermy

1. Introduction

Aluminum matrix (AM) composites are widely used in automotive, aerospace and military industries, due to their excellent mechanical properties such as strength, stiffness, wear resistance and good physical behaviors – light weight, high thermal and electrical conductivity [1–3]. Up to now, AM composites have been mainly reinforced with SiC and Al₂O₃ additions [4–6]. More recent studies have considered, however, the possibility of applying other reinforcements such as TiC and VC [7], Si₃N₄ [8,9] and AlN [10,11], synthesizing in this way composite materials with different characteristics thanks to their individual properties. Among the rein-

forcements mentioned above, AlN possesses excellent conductivity, low thermal expansion (similar to that of silicon), high hardness, high elastic modulus and good oxidation resistance at elevated temperatures [12,13]. These characteristics suggest AlN as an appropriate reinforcement not only for mechanical applications, but also for more special aims for e.g. for semiconductor packing in aerospace structures [14,15].

For producing Al/AlN composites, several fabrication methods are known: pressure or pressureless metal infiltration [16], squeeze casting [17], and mechanical alloying [18,19]. The main drawback of these methods is the usage of AlN – an expensive raw material.

In the present study, a method for producing aluminum matrix composite material with a high content of AlN is proposed based on aluminothermy. The potential advantage of this method is its low processing cost, simplicity and the possibility for near-net shaping.

2. Experimental procedure

For the synthesis of the Al/AlN composite material, fine powders (mean particle size < 40 μm) of aluminum and of quartz glass were mixed and heat treated in a corundum crucible in a muffle furnace for 6 hours at 1100°C in air. The quartz glass contained less than 0.1% of Na₂O as an admixture. The ratio of aluminum to quartz glass powders in the mixture was 85 : 15. As a reference, pure Al powder without the addition of quartz glass was also heated in another corundum crucible under the same conditions. During the heat treatment a periodical inspection of the behavior of the two samples was undertaken. It was established that above the Al melting point, the Al/quartz glass mixture began to glow as the glowing intensity increased with temperature. No glowing was observed, however, in the reference sample.

After cooling down to room temperature, both samples thus obtained were cut. The fresh cut surfaces were investigated by X-ray Diffraction (Bruker D8 Advance equipped with Copper tube ($\text{CuK}\alpha$) and LynxEye PSD detector) determining in this way the phase composition of the samples in the bulk. Scanning Electron Microscopy (MERLIN FE-SEM) was used to investigate the inner structure of the composite material.

3. Results and discussion

The fresh cut surfaces of the composite material (designated as bulk in Table 1) and of the reference sample exhibit strong metal glitter. Indeed, a high content of aluminum is found in both samples by XRD analysis (Figs. 1 and 2 and Table 1) proves that during the heat treatment a large part of aluminum remains unreacted. As seen in Table 1 the composite material contains about 30 vol. % AlN particles and small amounts $\alpha\text{-Al}_2\text{O}_3$ and Si phases, while in the reference sample no AlN crystal phase is found: beside the high content of metal aluminum (73 vol. %), the presence of about 27 vol. % of $\alpha\text{-Al}_2\text{O}_3$ is only registered. This proves that the addition of SiO_2 in the form of silica glass powder is of a decisive significance for the synthesis of AlN crystal phase.

Table 1. Data on the phase composition (in vol. %) of the initial Al powder, of the composite material and of the reference sample in the bulk, obtained by Rietveld analysis. The composition of the surface of Al/AlN material is also given

Sample	Al	Al_2O_3	Si	AlN
Initial Al powder	100	–	–	–
Al/AlN composite material (bulk)	51	8	8	33
Al/AlN composite material (surface)	49	2	9	39
Reference sample (bulk)	73	27	–	–

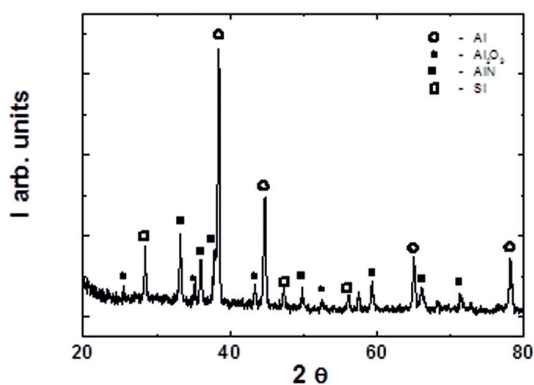


Fig. 1. XRD patterns from fresh cut surfaces of the Al/AlN composite material

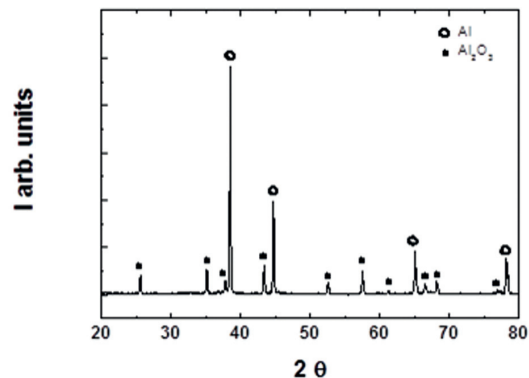


Fig. 2. XRD patterns from fresh cut surfaces of the reference sample

The surface of the composite material which was in a contact with the furnace atmosphere (designated as surface in Table 1) was also studied by XRD analysis. The composition of the surface layer is also presented in Table 1. As seen in the Table, the degree of nitriding is higher on the sample surface than in its bulk.

In Figure 3, a SEM micrograph from the fresh cut surface of the composite material synthesized is presented. Many darker particles with irregular forms and sizes between 20 and 50 μm are visible which are embedded in the brighter matrix. The results of microprobe analysis show that in the particles, the ratio $C_{\text{Al}}/C_{\text{N}}$ of aluminum C_{Al} and nitrogen C_{N} content is nearly equal to 1 which accounts for the X-ray data evidence that these particles are AlN particles embedded in an Al-Si alloy matrix.

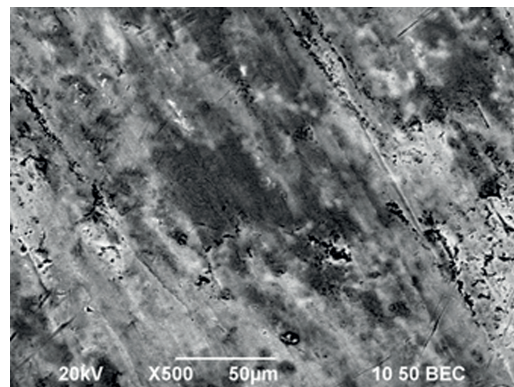
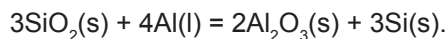


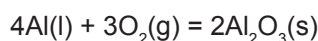
Fig. 3. SEM micrograph from the fresh cut surface of the aluminum matrix composite material

The results presented show that by heating a mixture of fine aluminum and silica glass powders at a relatively low temperature (1100°C) in air it is possible to synthesize an aluminum matrix composite material containing a high percentage of AlN crystal phase. It turns out that without the addition of silica glass powder no synthesis of AlN phase takes place, only a significant part (about 27 vol. %) of aluminum is oxidized to Al_2O_3 . At the present stage of our investigations it is difficult to clarify

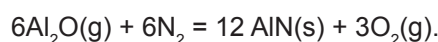
the observed differences in the behavior of the pure Al powder and the mixture of aluminum and quartz glass powders. One possible explanation is the substantial temperature increase observed above the Al melting point in the Al/quartz glass mixture, most probably due to the high exothermic reaction between SiO_2 and Al melt:



The above reaction initiates the formation of aluminum suboxide Al_2O [20]:



which promotes the formation of AlN crystal phase:



Moreover, it should be also taken into account that the silicon is characterized by a thermal expansion coefficient close to that of AlN crystal phase and silicon crystallites may play a role of active nucleation centers in respect to the formation of AlN phase.

4. Conclusions

A method for synthesis of aluminum matrix composite material is proposed based on aluminothermy. This method is characterized by low processing cost, simplicity and the possibility for near-net shaping.

The method proposed can also be used for synthesis of other aluminum matrix composite materials containing, besides AlN, other ceramic reinforcement phases. The properties of these composite materials can be tailored by choosing an appropriate composition of the initial powder mixture for aluminothermic synthesis.

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