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Structure formation of AlMg2-AlN composite cast in electromagnetic field

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ABSTRACT

Purpose: Basic material concept, technology and some results of studies on aluminum matrix composite with dispersive aluminum nitride reinforcement was shown. Studied composites were manufactured with use f ex-situ technique and powder metallurgy.
Design/methodology/approach: Aluminum nitride powder was manufactured in process of self-evolving high-temperature synthesis SHS. Composite powder Al-AlN was obtained using mechanical alloying. Composite castings were manufactured in stir casting process and poured into graphite moulds under external electromagnetic field. For powder and composite structure characterization some methods were used, including: light microscopy, scanning microscopy, X-ray analysis, characteristic X-radiation analysis and quantitative analysis of selected composite regions. Composite structure and reinforcement distribution was compared with use of quantitative analysis.
Findings: Morphology and diffraction pattern of aluminum nitride powder was shown. Typical structure of studied composites with microanalysis results was indicated. Influence of electromagnetic field on structure and aluminum nitride dispersion change was represented.
Practical implications: Application of joint casting technique, powder metallurgy and electromagnetic field enabled control of reinforcement dispersion as well as the metal matrix structure.
Originality/value: Studies results confirmed the concept proposed for composite manufacturing.
Keywords: Casting; Solidification; Composite; Reinforcing particles morphology; Simulation

1. Introduction

In proposed material and technological concept for composite manufacturing assumption was made, that joining different techniques of casting process, powder metallurgy and application of rotational electromagnetic field during crystallization would enable proper manufacturing conditions and possibilities of dispersive structure formation [1-11]. The main aim of the studies was the manufacturing of composite consisting of aluminum matrix and dispersive aluminum nitride reinforcement with different particles size. Moreover, authors described and compared structure of composites obtained in consecutive processes. Range of studies included:

- development of material and technological concept for composite with tailored structure,
- determination of conditions and technological parameters for powder preparation and manufacturing of composite casting reinforced with aluminum nitride,
- structure and phase composition determination of initial materials and resulting composite.

2. Methodology and results

It was assumed, that as an inexpensive substrate for high-temperature synthesis of aluminum nitride mixture of aluminum powder and chips can be used. Aluminum nitride sinter was crushed in Petch jaw crusher and milled for two hours in was added rotational-vibrating mill. Sprayed aluminum powder with grade of 70 in quantity of 50% mass. and mechanical alloyed for four hours in the same mill. Composite Al-AlN powder was introduced into the liquid AlMg2 alloy in quantity of 40% mass. according to stir casting procedure. Following castings was remelted and solidified under action of rotational electromagnetic field with magnetic induction of B=0,2 mT on mould surface, angular velocity of ω=157 s^{-1} and action time of 20 s and 40 s. Powder structure was observed and analyzed using light and scanning microscopes. Chemical composition in composite micro-regions was determined using characteristic X – radiation analysis (EDX).

Phase composition for powder samples and composite was studied with use of diffraction patterns obtained from Joel diffraction instrument. Copper lamp was employed with use of carbon monochromator. Quantitative analysis was conducted with magnification 50× using MetIlo 3 software according to scheme of regions shown in Fig. 1. For separation of aluminum nitride agglomerates during this analysis from matrix background special image detection technique was applied.

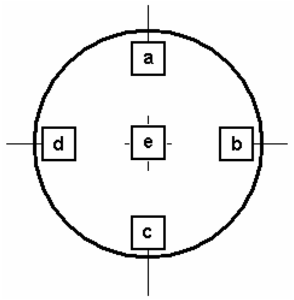


Fig. 1. Scheme of regions studied during surface analysis

Composite structure analysis conducted on castings with aluminum matrix and aluminum nitride reinforcement enabled formulation of several conclusions regarding technological parameters of composite manufacturing. Diversified size of AlN powder after crushing and its surface morphology enables obtaining also after milling multi-modal mixture of particles, which are next mechanically alloyed with aluminum powder. It can be assumed, that elongation of crushing time for AlN sinter could increase number of particles with nano-size. Use of different mill and high-energy attritor would enable composite Al-AlN powder with more dispersive structure. With such assumption application of such technological procedure in composite manufacturing would enable obtaining composite with very high dispersion of reinforcement, not achievable in standard stir casting technique.

Evaluating composite structure it was confirmed, that reinforcing phases has had tendency for agglomeration, especially of phases with highest dispersion. Presence of small discontinuities in castings and inhomogeneity of reinforcement distribution depend on technological parameters of powder and composite manufacturing, type of reinforcing phases, reinforcement wettability, stir methods and crystallization and structure forming conditions in following stages of crystallization process. Results of structure studies confirmed appropriateness of rotational electromagnetic field application for achievement of desired composite structure and showed direction for further studies. It must be pointed out, that composite structure changed in consecutive stages from large agglomerates in more homogenous with high quantity of eutectic inclusions which also had reinforcing capabilities.

In Fig. 2a structure of AlMg2-AlN was shown obtained without use of electromagnetic stiring during crystallization. Fig. 2b and 3 show the same composite structure after application of electromagnetic field. Decay of interface between matrix and powder agglomerates can be observed. Distinct aggregates of powder particles were distracted in metal matrix and distance between reinforcing particles was increased.

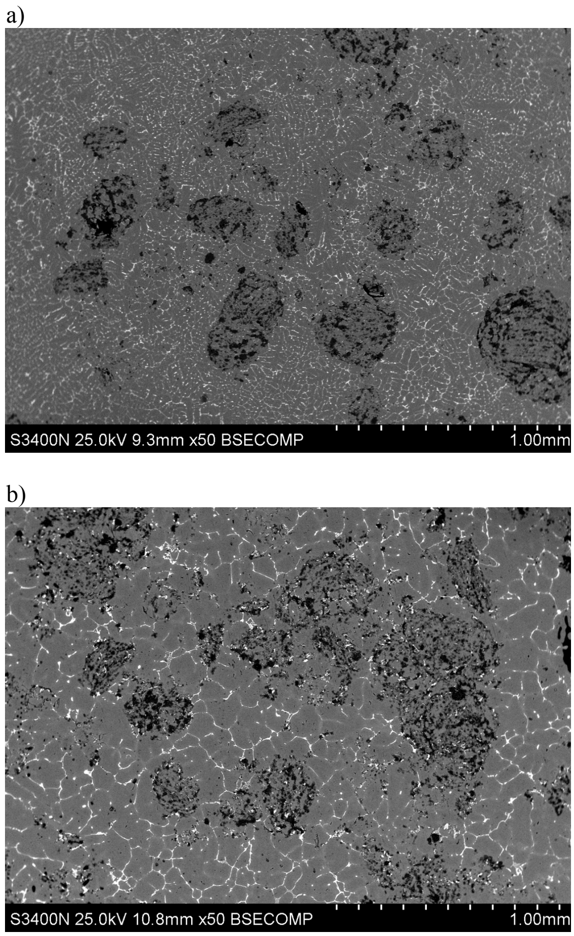


Fig. 2. Examples of structure before and after application of electromagnetic stirring: a) AlMg-AlN composite casting, b) the same composite after application of electromagnetic field during crystallization of metal matrix

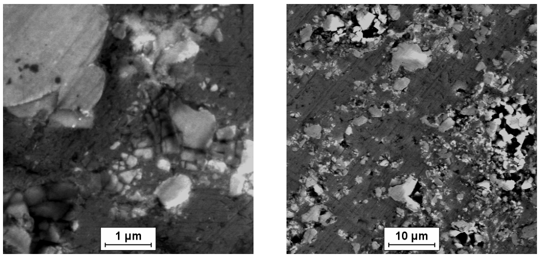


Fig. 3. Examples of structure after application of electromagnetic stirring showing particles distribution at different gradation

Obtained effect was sufficient in presented preliminary studies. Presented technique is potentially very useful especially in cases of high content of reinforcement with different gradation.

In Fig. 4 selected region was shown with typical structural components taken for phase analysis (Fig. 4a). Because of technical limitations during point analysis the quantitative analysis of nitrogen content in nitride phases was not obtained, but its presence was confirmed (Fig. 4b and c). Moreover, presence of oxygen phases was observed (Fig. 4d), what is valid when taking into account powder manufacturing process. In the same way presence of other structural components was observed (Fig. 4e and f).

Composite surface was studied using Hitachi S3400N scanning microscope with EDS system of Noran Instruments. For reinforcing particles detection the technique of back distracted electrons was used. For image processing MetIlo 3 software system was used. During quantitative analysis following parameters were studied: surface area A [mm^2], perimeter P [mm], shape coefficient calculated according to $\xi=4\pi(A/P^2)$ [1/1], surface content [%].Selected results of quantitative analysis was shown in table 1.

Table 1.
Results of quantitative analysis for reinforcing particles in Al-AlN composite

	image „a”	image „b”	image „c”	image „d”	image „e”	AVE
die casting						
surface area [mm^2]	0,00020	0,00024	0,00023	0,00018	0,00016	**0,00020**
perimeter [mm]	0,040	0,047	0,045	0,037	0,034	**0,041**
shape coefficient	0,52	0,54	0,53	0,55	0,52	**0,53**
surface content [%]	14,38	19,77	16,88	12,86	11,70	**15,12**
casting manufactured with use of electromagnetic stirring						
surface area [mm^2]	0,00008	0,00008	0,00007	0,00009	0,00007	**0,00008**
perimeter [mm]	0,015	0,015	0,013	0,017	0,013	**0,015**
shape coefficient	0,29	0,26	0,22	0,26	0,25	**0,26**
surface content [%]	3,25	5,23	2,60	6,77	3,33	**4,24**

a) b) c) d) e) f)

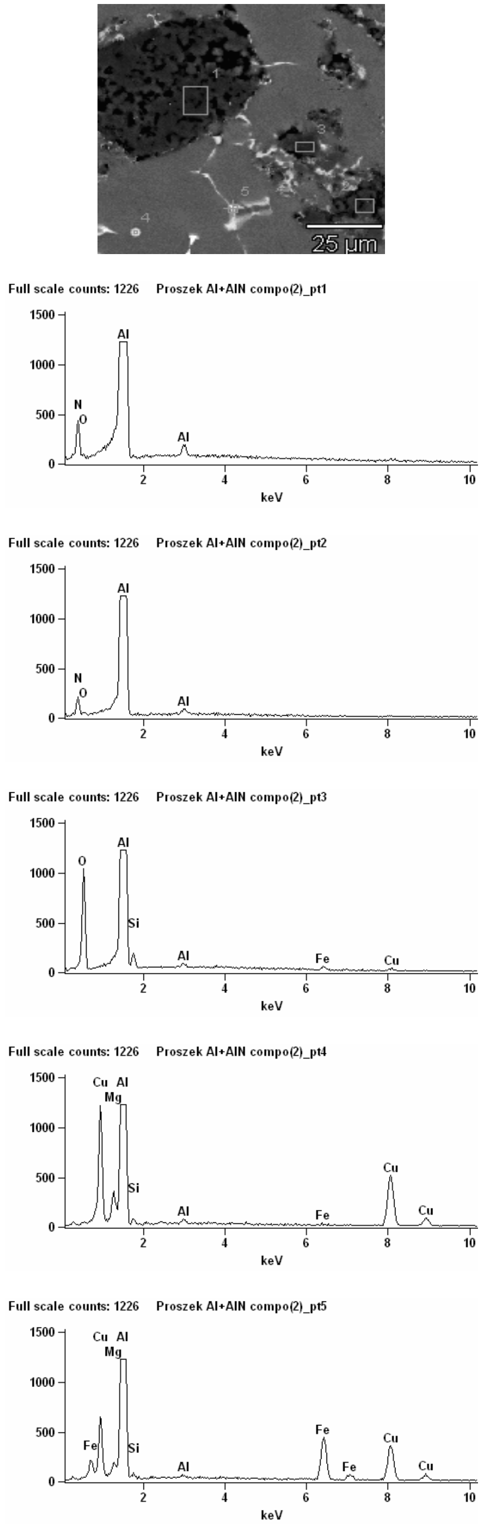
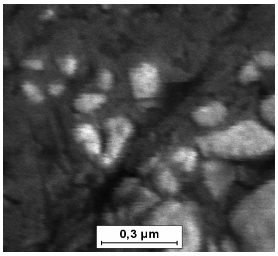


Fig. 4. EDX microanalysis results showing elements distribution in composite micro-regions. Figures b)÷f) relate to measuring points 1÷5, respectively in fig. 4a)

Based on conducted calculations, decrease in object quantity can be seen. It results from agglomerates distraction in composite volume. Average surface area and other factors of reinforcing particles also decreased. Some of the structural components can be out of the measuring range – these of nano-size. Proof of existence of such particles is shown in fig. 5 registered at 50000x magnification.



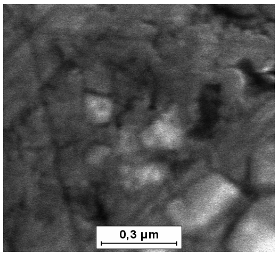


Fig. 5. Structure of composite at 50 000 x magnif

3. Conclusions

Application of high-temperature synthesis for preparation of ceramic and metal-ceramic phases, consequently composite powders and ex-situ MMC composites together with electromagnetic field is an effective process. It must be pointed out, that such joint process enables possibilities for manufacturing composites with diverse reinforcement dispersion in range of micro to even nano-size reinforcing particles. Conducted studies described in the paper on casting manufacturing with dispersive aluminum nitride particles showed agglomeration tendency of reinforcing particles and potential possibilities of electromagnetic field application for limitation of such phenomena. Use of quantitative metallography for composite structure characterization enables description of electromagnetic field influence on reinforcing particles distribution and dispersion in very effective way.

Further studies will include correction of technological parameters in manufacturing process and modification of composite matrix structure for optimized tribological and mechanical properties. Correction includes also changes in chemical composition of metal matrix and application of hybrid multi-phase dispersive reinforcement [4]. Obtained results confirmed appropriateness of assumed material and technological concept for liquid composite dispersion manufacturing and its crystallization under action of rotational electromagnetic field.

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