Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 24 ISSUE 2 October 2007

Application of pressure infiltration to the manufacturing of aluminium matrix composite materials with different reinforcement shape

L.A. Dobrzański [a,*], M. Kremzer [a], A. Nagel [b]
[a] Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
[b] Faculty of Mechanical Engineering, Aalen University, Beethoven str. 1, D-73430 Aalen, Germany
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

Received 20.04.2007; published in revised form 01.10.2007

Manufacturing and processing

ABSTRACT

Purpose: The purpose of this work is to investigate the influence of reinforcing phase's shape on structure and properties of composite materials with aluminium alloy matrix.
Design/methodology/approach: The material for studies was produced by a method of pressure infiltration of the porous ceramic framework. In order to investigate the influence of reinforcing phase's shape the comparison was made between the properties of the composite material based on preforms obtained by Al_2O_3 Alcoa CL 2500 powder sintered with addition of pore forming agent in form of carbon fibres Sigrafil C 10 M250 UNS from Carbon Group company and composite materials based on much more expensive commercial fibrous preforms. The matrix consisted of cast aluminium alloy EN AC – AlSi12. The observations of the structure were made on the light microscope and in the scanning electron microscope. The strength properties were established on the basis of static tensile tests.
Findings: The composite materials, obtained on the basis of ceramic preforms consisted of Al_2O_3 particles, are showing better strength properties in comparison to materials obtained by the fibrous preform infiltration.
Practical implications: The composite materials made by the developed method can find application as the elements of devices where beside the benefits from utilizable properties the small weight is required (mainly in aircraft and motorization industries).
Originality/value: The obtained results show the possibility of manufacturing the composite materials by the method of porous sintered framework pressure infiltration based on the ceramic particles, characterized with the better properties than similar composites reinforced with fibres.
Keywords: Composites; Ceramic preforms; Infiltration

1. Introduction

The customer expectations and intense competition on automotive market are putting cars' producers in front of the increasing demands regarding the comfort and safety during the journeys. Engineers and designers wanting to match these expectations have to install in vehicles more and more newer and the latest systems which are increasing their weight making them less attractive from the economical and ecological point of view. The solution for the described problem is modern engineering materials among the others composite materials with light metals alloys matrix, providing lots of desired features along with comparatively low density. The usage of modern materials helps designers to avoid the compromise between comfort, safety and economical-ecological aspects and make their projects much lighter and sustain the required parameters [1].

Composite materials are different from many others available materials because of the possibility to design their properties accordingly to the closest desired requirements for the condition of the practical use. Producing and estimating the properties of the materials isn't simple and is connected with complicated engineer's calculations because it have be taken into consideration many parameters among which there are: components properties, their portion, type of connection between them, the used technique of manufacturing and its parameters, further treatment and many others [2-5].

Composite materials depending from their destination are produced in various different methods like casting, forming process, powder metallurgy, forming by spraying, gas phase deposition, CVD and others. Composite materials with oriented wires or ceramic fibres are usually produced by a method of casting and forming process. First of them consists in self-acting or pressured infiltration with liquid metal preforms being the porous framework consisted of wire's or fibre's convolution with high melting point. Forming process method is based on preliminary parallel wire winding on frames with further electrolytic sedimentation on the matrix metal wire, frames folding and block's metal pressing in a temperature which allows for diffusive connection of metallic matrix with evenly placed fibres [5-8].

Among the most popular techniques for manufacturing the metal composite materials it can be distinguish the already mentioned porous preforms infiltration as the specific kind of casting. This method connects the casting techniques (infiltration process) with powder metallurgy (preparation of porous sintered frameworks). Ceramic preforms are mostly made on the grounds of long or short (trimmed) fibres, but lately it can be observed the expansion of technologies with much more cheaper preforms mainly consisted of Al_2O_3 particles [8-12].

Producing the composite materials by the method of pressure infiltration of porous ceramic frameworks brings many advantages in which it is worth to mention the possibility of producing the locally reinforced elements with a near net shape and a good quality of surface, high performance of the process with low production costs as well as short time of contact with liquid metal with reinforcement what often prevent its degradation. These benefits of the described technology have interested numerous group of research centres in many countries of the world what resulted in various scientific works [12-15] and practical implementations on a large industrial scale.

The purpose of this paper is to compare the structure and properties of the composite materials produced by the method of pressure infiltration of porous ceramic frameworks obtained by the sintering of Al_2O_3 powder with the composite materials on the grounds of much more expensive commercial fibrous preforms.

2. Experimental procedure

The material for investigation was produced by he method of pressure infiltration of porous ceramic frameworks with liquid aluminium alloy. The composites matrix consisted of euthetic alloy EN AC – AlSi12 and as the reinforcement the porous ceramic frameworks waere used accordingly consisted of Al_2O_3 particles and fibres.

Ceramic preforms from Al_2O_3 particles were produced by Aloca CL 2500 powder sintering method with addition of pore forming agent in form of carbon fibres Sigrafil C 10 M250 UNS from SGL Carbon Group company. The properties and chemical composition of the used ceramic powder are shown in Table 1. Producing the ceramic preforms included preparation of powder and carbon fibres mixture, their pressing and sintering. The Al_2O_3 powder was wet grinded in ball mill to destroy particles agglomerations. Into the suspension the 40% addition of mass carbon fibres were added and polyvinyl alcohol Moviol 18-8 soluted in water (binding agent). Mixture of powder prepared in such a way was dried by freezing and water sublimation in low pressure. Dry powder was sieve through a sieve No 250 µm, and then placed onto the flat surface and sprayed with destilated water to activate the polyvinyl alcohol. After 24h the powder was submitted to uniaxial pressing with laboratory Fontune TP 400 hydraulic press fitted with 45x65 mm. steel form. The pressure was 100MPa and pressing time was 15s. Mouldings were sintered in “Gero” pipe furnace in air atmosphere (20 l/min). The temperature during the sintering process was ensuring the carbon fibres degradation (heating by 10h in temp. 800 ºC) and Al_2O_3 powder sintering in temperature of 1500 ºC by 2h. The portion of the porous (ceramic phase) in preforms was established on the basis of geometric measurement of their weight with the known Al_2O_3 particles density. The porosity of the received semi-finished products was around 75% (25% for the ceramic phase). For the comparison of properties of the composite materials on the grounds of the produced frameworks with materials reinforced by fibrous preforms for further studies the commercial semi-finished products were used with 25% portion of Al_2O_3 fibres.

Both type of preforms were heated in furnace to temperature of 800 ºC. Covered by graphite form was warmed up to 450 ºC (maximal temperature of the press plates) and then fulfilled with preform and liquid alloy EN AC – AlSi12 with temperature of 800 ºC. The whole was covered by the stamp and placed in hydraulic plate press Fontune TP 400. Pressing speed was 17 mm/s and maximal pressure was 100MPa. After 120 s the weight was removed and the samples removed from the form were cool down under pressured stream of air.

Metallographic examinations of the composite materials with aluminium alloy EN AC – AlSi12 matrix reinforced by Al_2O_3 fibres and particles were made on the light microscope Zeiss Axiophot to exam the structure and infiltration level.

Fractography examinations of the composite materials were made on the scanning electron microscope Zeiss Supra 25.

The static tensile tests were made on the universal strength machine Zwick Z100 at the room temperature accordantly to PN-EN 10002-1:2004 standard [16].

Table 1.
Properties and chemical composition of Alcoa CL 2500 powder

Diameter D50,µm	Density, g/cm^3	Mean mass concentration of elements, wt.%						
		Al_2O_3	Na_2O	Fe_2O_3	SiO_2	CaO	B_2O_3	Others
1,80	3,98	99,80	0,05	0,02	0,01	0,01	0,01	0,10

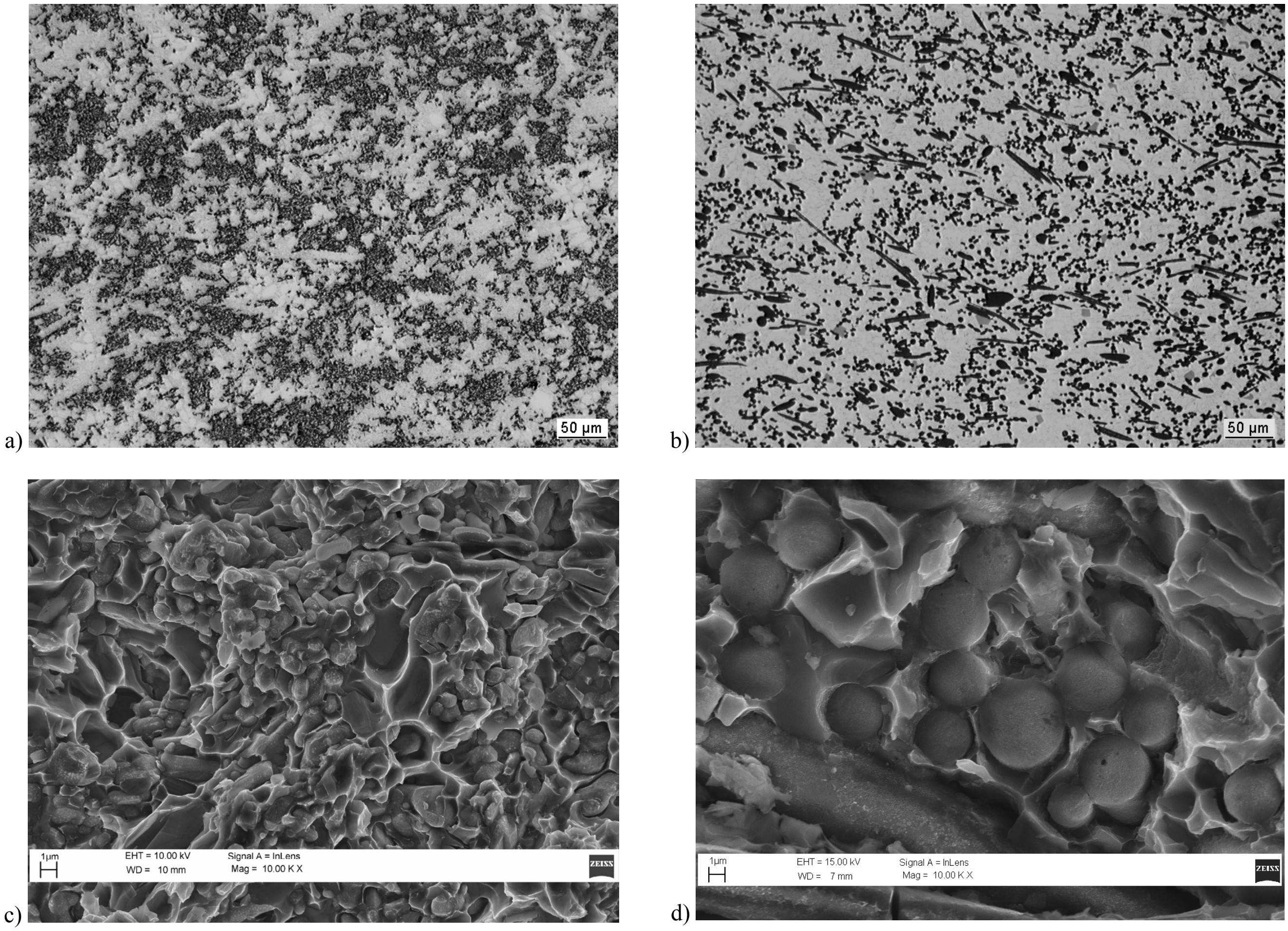

Fig. 1. Structure of the composite material with the aluminium alloy matrix reinforced with: a) the Al_2O_3 ceramic particles and b) fibres c), d) microstructures of the fracture, respectively

3. Experimental results and their discussion

The metallographic observations of the obtained composite materials based on preforms consisted of Al_2O_3 particles (Fig. 1a) as well as fibrous preforms (Fig. 1b) allow to notice the evenly distribution of reinforcing phase in the matrix. Moreover, on the base of the structure of both materials it can be forecast that the composite material reinforced by ceramic particles, will have higher crack resistance along the grain boundaries metal-ceramic, because every particle is a barrier for spreading crack however along the fibre this process will occur on the comparatively long distance (fibre's length) without any obstacles.

On the basis of fractography observations (Fig. 1 c, d) it was found that infiltration process takes place at full level what have been proved by the lack of pores not filled with metal. Fracture has mixed characteristic, elastically deformed matrix around the reinforcing phase and brittle on the metal-ceramic boundaries.

On the base of static tensile tests the strength of the obtained composite materials and the matrix material (EN AC – AlSi12 alloy) were established. The matrix is characterised by 198MPa tensile strength, used fibrous reinforcement with 25% volume fracture of fibres improves this parameter up to 234MPa, however the material based on the developed preforms is characterized by 289MPa strength. In the last case the main mechanism which improves the tensile strength is most probably dispersion strengthening. Small Al_2O_3 particles with 1 – 2 µm diameter stop dislocation movement in the matrix improving its properties.

4. Conclusions

The observations of the obtained composite materials structures shown uniform distribution of reinforcing phase in the metal matrix. It has also been proven that pressure infiltration is taking place at full level what confirms lack of pores in the material. Moreover it also says that pores in preforms have the open character and their dimensions allow the liquid metal to flow. On the base of the static tensile test it could be observed significant increase of the strength of the material based on the ceramic preform consisted of Al_2O_3 particles in comparison with the matrix. This material is characterised also by the better strength in comparison with the similar reinforced material with much more expensive ceramic fibres.

It has been proven that the developed technology of manufacturing the composite materials based on pressure infiltration of the porous framework sintered with liquid alloy of aluminium EN AC – AlSi12 provides the required structure and increases the strength over 50% in comparison with matrix. Moreover the materials based on the developed ceramic preforms are characterized by the better strength than the materials reinforced with fibrous preforms and without any doubts can be used as cheaper alternative material. Further studies over the developed material are still in progress in order to describe the tribology properties and corrosion resistance level.

Acknowledgements

Investigations were partially financed within the framework of the Polish Ministry of Scientific Research and Information Technology 3 T08A 041 30 grant headed by prof. L.A. Dobrzański

References

[1] L.A. Dobrzanski, M. Krupiński, J.H. Sokołowski, P. Zarychta, A. Włodarczyk-Fligier, Methodology of analysis of casting defects, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 267-270.
[2] A. Dolata-Grosz, M. Dyzia, J. Śleziona, Solidification and structure of heterophase composite, Journal of of Achievements in Materials and Manufacturing Engineering 20 (2007) 103-106.
[3] A. Dolata-Grosz, J. Wieczorek, Tribological properties of hybrid composites containing two carbide phases, Archives of Materials Science and Engineering 28 (2007) 149-155.
[4] M.F. Ashby, D.R.H. Jones, Engineering Materials 2 – Forming of the structure and properties, materials selection, WNT, Warsaw 1998 (in Polish).
[5] A. Boczkowska, J. Kapuściński, Z. Lindemann, D. Witemberg-Perzyk, S. Wojciechowski, Composites, Warsaw University of Technology Press, Warszawa, 2003 (in Polish).
[6] J. Adamczyk, Engineering of metalic materials, Silesian University of Technology Press, Gliwice 2004 (in Polish).
[7] A. Dolata-Grosz, B. Formanek, J. Wieczorek, Cast aluminium with Fe-Cu-TiC composite powder reinforcement, Proceedings of the 11th International Scientific Conference CAM3S, Gliwice-Zakopane 2005, 295-300, (CD-ROM).
[8] K. Naplocha, A. Janus, J.W. Kaczmar, Z. Samsonowicz, Technology and mechanical properties of ceramic preforms for composite materials, Journal of Materials Processing Technology 106 (2000), 119-122.
[9] A. Mattern, B. Huchler, D. Staudenecker, R. Oberacker, A. Nagel, M.J. Hofmann, Preparation of interpenetrating ceramic-metal composites, Journal of the European Ceramic Society 24 (2004) 3399-3408
[10] L.A. Dobrzański, M. Kremzer, A.J. Nowak, A. Nagel, Composite materials based on porous ceramic preform infiltrated by aluminium alloy, Journal of of Achievements in Materials and Manufacturing Engineering 20 (2007) 95-98.
[11] L.A. Dobrzański, M. Kremzer, A. Nagel, B. Huchler Fabrication of ceramic preforms based on Al_2O_3 CL 2500 powder, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 71-74.
[12] N. Altinkok, A. Demir, I. Ozsert, Processing of Al2O3/SiC ceramic cake preforms and their liquid metal infiltration, Composites 34 (2003) 577-582.
[13] A. Alonso, A. Pamies, J. Narciso, C. Garcia-Cordovilla, E. Louis, Evaluation of the wettability of liquid aluminum with ceramic particulates (SiC, TiC, Al_2O_3) by means pressure infiltration, Metallurgical Transactions 24A (1993) 1423-1432.
[14] G.G. Kang, Y.H. Seo, The influence of fabrication parameters on the deformation behavior of the preform of metal-matrix composites during the squeeze-casting processes, Journal of Materials Processing Technology 61 (1996) 241-249.
[15] L.M. Peng, J.W. Cao, K. Noda, K.S. Han, Mechanical properties of ceramic-metal composites by pressure infiltration of metal into porous ceramics, Materials Science and Engineering A374 (2004) 1-9.
[16] Polish standard, PN-EN 10002-1:2004, Metallic materials - Tensile testing - Part 1: Method of test at ambient temperature.