11th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2007, Hammamet, Tunisia, 05-09 September, 2007.

# INFLUENCE OF REINFORCEMENTS SHAPE ON THE STRUCTURE AND PROPERTIES OF Al-$Al_2O_3$ COMPOSITE MATERIALS

**Leszek A. Dobrzański, Marek Kremzer**
**Institute of Engineering Materials and Biomaterials, Faculty of Mechanical Engineering, Silesian University of Technology**
**ul. Konarskiego 18a, 44-100 Gliwice,**
**Poland**

**Alwin Nagel**
**Department of Mechanical Engineering and Material Sciences, University of Aalen**
**Beethovenstr. 1, D-73430 Aalen**
**Germany**

## ABSTRACT
*The paper presents investigation results of reinforcements shape influence on the structure and properties of composite materials fabricated by pressure infiltration method. Casting aluminum alloy EN AC – AlSi12 was used as composite matrix whereas ceramic preforms based on $Al_2O_3$ particles and short alumina fibres as reinforcement. Preforms based on particles were manufactured by sintering method of $Al_2O_3$ Alcoa CL 2500 powder with the addition of pore forming agent. As fibres reinforcement were also used commercials semi-finished products fabricated by sintering method but with addition of silica binder.*
*The metallographic examination of ceramic preforms and obtained materials were made on the light microscope and on the scanning electron microscope (SEM). Tensile and hardness tests of the obtained materials were also carried out. The results indicate the possibility of obtaining of new materials based on ceramic particles preforms being the cheaper alternative for fibres reinforced composites.*
**Keywords:** Composites, Infiltration, Ceramic preforms

## 1. INTRODUCTION
In recent years, steel parts have been replaced with aluminium or magnesium alloy parts by the need to save energy by using lightweight materials mainly in the field of transportation. The industrial application of aluminium and magnesium alloys enhances the efficiency of machines and reduces energy consumption. Light metals alloys have low elastic modulus, high coefficient of thermal expansion and low wear resistance compared with steels. However, these alloys reinforced with ceramic fibres or particles have high elastic modulus and low coefficient of thermal expansion due to the properties of the reinforcement. Producing and estimating the properties of composite 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 [1, 2, 3, 4].
Metal matrix composites reinforced with ceramic fibres or particles have become of great interest because of the combined effects of metallic and ceramic materials relative to the corresponding monolithic alloys. Thus, various fabrication methods have been developed, such as powder metallurgy and casting techniques. Furthermore, in recent years there has been a growing interest in the development of pressure infiltration method, being a connection between the casting techniques (infiltration process) and powder metallurgy (preparation of porous sintered frameworks) [5].

The pressure infiltration technique is based on the injection of a fully liquid melt into the ceramic porous preform. This method has recently attracted interest due to its relatively low cost and capability to produce net or near net shape fibre and particle reinforced or partially reinforced components. There have been many researches paying attention to the infiltration process and the relationships between the microstructures and the mechanical properties of metal matrix composites [6, 7, 8, 9, 10, 11].
The purpose of this paper is to exanimate the influence of the reinforcements shape on structure and properties of composite materials obtained by pressure infiltration of porous preforms contained ceramic fibres and particles.

## 2. MATERIAL AND EXPERIMENTAL PROCEDURE

The material for investigation was obtained by the method of pressure infiltration of porous ceramic frameworks with liquid aluminium alloy. The EN AC - AlSi12 eutectic aluminium alloy features the matrix material, whose chemical composition is presented in Table 1; whereas the porous preforms, consisted of $Al_2O_3$ particles and fibres were used as the reinforcement.
The ceramic particles preforms were manufactured by sintering of powder $Al_2O_3$ Alcoa CL 2500, whose characteristics are presented in Table 2, with the addition of pores forming agent in the form of carbon fibres Sigrafil C10 M250 UNS of Company SGL Carbon Group.

*Table 1. Chemical composition of EN AC-AlSi12 aluminium alloy (PN-EN 1706:2001)*

| Mean mass concentration of elements, wt.% | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Si | Cu | Mg | Mn | Fe | Ti | Zn | Ni | Pb |
| 12 | ≤0.15 | ≤0.1 | ≤0.55 | ≤0.65 | ≤0.2 | ≤0.15 | ≤0.1 | ≤0.1 |

*Table 2. 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 |

The manufacturing process of the ceramic preforms involved:
- preparation of $Al_2O_3$ powder and carbon fibres mixture,
- pressing of prepared mixture,
- sintering.

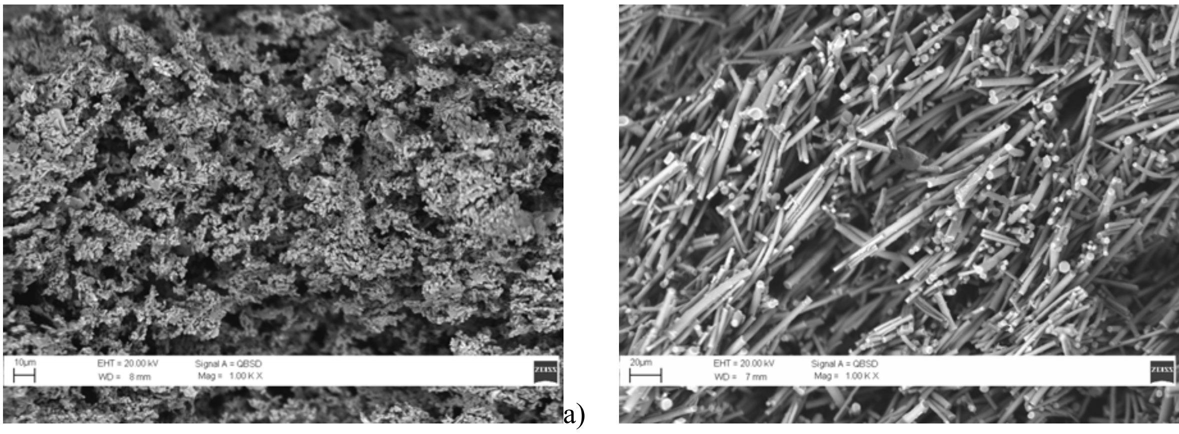
The porosity of the received semi-finished products was around 75% (25% for the ceramic phase). For the comparison of properties of the composite materials on the grounds of the produced frameworks with materials reinforced by fibrous preforms for further studies the commercial semi-finished products were used with 25% portion of $Al_2O_3$ fibres. Both type of preforms were heated up to the temperature of 800°C and next infiltrated with the liquid EN AC – AlSi12 alloy under 100 MPa pressure for 120 s.
Observations of the structure of preforms, distribution of the $Al_2O_3$ particles and fibres were carried out using the Zeiss Supra 25 scanning electron microscope. Metallographic examinations of the composite materials with the EN AC - AlSi12 aluminium alloy matrix reinforced with the $Al_2O_3$ fibres and particles were made on the Zeiss Axiophot light microscope to investigate their structure and infiltration extent. The static tensile tests were made on the universal strength machine Zwick Z100 at the room temperature according to PN-EN 10002-1:2004 standard. Hardness tests were made on Zwick / ZHR hardness tester in a HRA scale according to PN-EN ISO 6508-1:2006 standard.

## 3. RESULTS AND DISCUSSION

The preform's morphology observed in the scanning electron microscope is presented in Figure 1. Both types of preforms are chracterized by homogeniuous distribution of ceramic phase. In the case of obtained particulates preforms observations allowed revealing two main types of pores. The first are bigger and have been formed because of carbon fibres degradation, the second one are smaller and appear around singular ceramic particles and result from intentional lack of condensation (caused by using a greater pressure and higher sintering temperature).

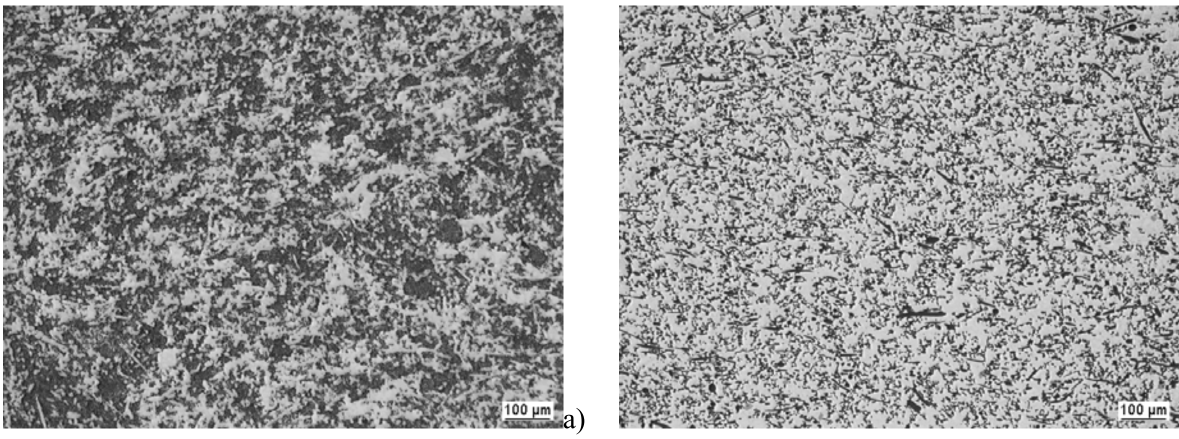
Results of metallographic examinations of the porous ceramics based composite materials obtained with the EN AC – AlSi12 alloy infiltration, carried out on the light microscope are presented in Fig. 2. Observations reveal, that infiltration process takes place at full level what have been proved by the lack of pores not filled with metal and homogeneous distribution of particles and fibres of the reinforcing material in the matrix.

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 198 MPa tensile strength, used fibrous reinforcement with 25% volume fracture of fibres improves this parameter up to 234 MPa, however the material based on the developed preforms is characterized by 289 MPa 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.




a) b)

*Fig. 1. The microstructure of ceramic preforms fracture: a) based on $Al_2O_3$ Alcoa CL 2500 powder, b) commercial based on sort $Al_2O_3$ fibres*




a) b)

*Fig. 2. Structure of un-etched micro section of the composite material with the aluminium alloy matrix obtained by infiltration of ceramic preforms: a) based on $Al_2O_3$ Alcoa CL 2500 powder, b) commercial based on sort $Al_2O_3$ fibres*

Basing on hardness tests of the composite material hardness was found to be 2.5 times higher compared to the EN AC – AlSi12 matrix material. The average matrix hardness is 19.19 HRA; whereas hardness values of the composite material fabricated by infiltration of the obtained particulate preforms and commercial fibrous preforms are 47.31 HRA and 47.29 HRA respectively.

## 4. CONCLUSIONS

The metallographic examinations on the scanning electron microscope carried out of the $Al_2O_3$ porous ceramic semi-finished products reveal that the particles and fibres in the preforms are distributed homogeneously. The metallographic observations of composite material manufactured by infiltration of ceramic preforms with liquid aluminium alloy show that the reinforced phase in matrix is uniformly distributed. More over it can be concluded that if the process of infiltration was complete, all pores are fulfilled with liquid matrix material.

Basing on hardness tests of the composite material hardness was found to be 2.5 times higher compared to the EN AC – AlSi12 matrix material. 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 characterized also by the better strength in comparison with the similar reinforced material with much more expensive ceramic fibres. It was found out that the developed technology of fabricating the composite material with the EN AC – AlSi12 alloy matrix reinforced with the $Al_2O_3$ particles and fibres, consisting in the infiltration of the ceramic preforms with the liquid aluminium alloy, ensures the required structure and mechanical properties, increased compared to the matrix, and – therefore – may find practical applications.

## 5. AKNOWLEMENTS

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

## 6. REFERENCES

[1] Kimura R., Yoshida M., Sasaki G., Pan J., Fukunaga H.: Influence of abnormal structure on the reliability of squeeze casting, Journal of Materials Processing Technology, vol. 130-131 (2002).,

[2] Dobrzański L.A., Kremzer M., Nagel A.: Application of pressure infiltration to the manufacturing of aluminum matrix composite materials with different reinforcement shape, Journal of Achievements in Materials and Manufacturing Engineering, vol. 24-2 (2007).,

[3] Dobrzański L.A., Kremzer M., Golombek K., Nagel A.: Aluminium matrix composites fabricated by pressure infiltration process, Inżynieria Materiałowa (2007) (in print).,

[4] Nishida Y.: Fabrication and recycling of aluminium metal matrix composites, Institute of Physic Publishing, Bristol and Philadelphia 2005.,

[5] Lee K.B., Ahn J.P., Kwon H.: Characteristics of AA6061/BN composite fabricated by pressureless infiltration technique, Metallurgical and Materials Transactions, vol. 32A (2001).,

[6] Kang C.G., Seo Y.H.: 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, vol. 61 (1996).,

[7] Carreno-Morelli E., Cutart T., Schaller R., Bonjour C.: Processing and characterization of aluminium-based MMCs produced by gas pressure infiltration, Materials Science and Engineering, vol. A251 (1998).,

[8] Cornie, James A.: Advanced pressure infiltration casting technology produces near-absolute net-shape metal matrix composite components cost competitively, Materials Technology vol. 10 3-4(1995).,

[9] Garbellini O., Morando C., Biloni H., Papacio H.: Infiltration of Saffil alumina fiber with AlCu and AlSi alloys, Scripta Materialia, vol. 41/2 (1999).,

[10] Konopka K., Szafran M.: Fabrication of $Al_2O_3$-Al Composites by infiltration method and their characteristic, Journal of Materials Processing Technology, vol. 175 (2006).,

[11] Dobrzański L.A., Kremzer M., Nowak A.J., Nagel A.: Composite materials based on porous ceramic preforms infiltrated by aluminium alloy, Journal of Achievements in Materials and Manufacturing Engineering, vol. 20 (2007).