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POROUS CERAMIC - METAL COMPOSITES OBTAINED BY INFILTRATION METHODS

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Preliminary Note – Prethodno priopćenje

A pressure-vacuum infiltration (T = 720 °C, p = 15 MPa, t = 15 min) and gas-pressure infiltration (GPI) in an autoclave (T = 700°C, p=4 MPa, t=5 min) were applied for infiltration of porous Al_2O_3 ceramics by cast aluminum alloy. Effect of the method of the infiltration on the microstructure and mechanical properties of ceramic-metal composites, was studied. Ceramic preforms were formed by method of copying the cellular structure of the polymer matrix. The results of the X-ray tomography proved very good infiltration of the pores by the metal for each method.

Key words: porous ceramics, cast aluminum alloy, composite, pressure infiltration

INTRODUCTION

Interpenetrating composites have both phases connected in all three dimensions, which can result in substantially different properties. However, high mechanical properties of composites depend on their microstructure after infiltration [1-3]. Stress concentration around large defects and voids, residual stresses and fracture influence on strength behaviour of composites. The most important way to achieve composites characterized by unusual properties is infiltration of a second phase into porous materials that display complete pores interconnectivity. The degree of porosity, the size and shape of the cells, the size of the windows between them and the nature of the struts separating them are factors that can be designed and influence the properties of composites with interpenetrating phases [1-7]. This work is part of an extensive program of research on the effects of infiltration parameters on the microstructure and mechanical properties of ceramic-metal composites.

In the paper the influence of the method of ceramics by AlSi12CuMgNi aluminum alloy on compressive strength, hardness and Young's modulus of composites was presented.

MATERIALS AND METHODS

The ceramic preforms were manufactured in the Institute of Ceramics and Construction Material by sintering of RA-207LS Al_2O_3 powder supplied by Alcan Chemicals. The chemical composition of aluminum oxide was Al_2O_3 (99,8 wt.%), CaO (0,02 wt.%), SiO_2 (0,04 wt.%), MgO (0,04 wt.%), Fe_2O_3 (0,03 wt.%), Na_2O (0,07 wt.%). For each ceramic preforms the porosity was at the same level, approximately 72 vol.%. Porous aluminum oxide preforms were formed by the method of copying the cellular structure of the polymer matrix [4 - 6]. Three types of polyurethane sponges, differing in density and size of pores were exploited: 60, 45 and 30 pores per inch (ppi). This results in the fabrication of preforms with pore sizes varying from 300 to 1 000 µm.

A pressure-vacuum infiltration on the Degussa press and gas-pressure infiltration (GPI) in an autoclave designed and built at the Faculty of Materials Science and Metallurgy, Silesian University of Technology (PL) were applied for infiltration of ceramic preforms by EN AC- AlSi12CuMgNi (AK12) cast aluminum alloy [6]. Composition of the alloy used for infiltration was: Si - 12 wt.%, Fe - 0,44 wt.%, Cu - 1,08 wt.%, Mn - 0,16 wt.%, Mg - 1,28 wt.%, Zn - 0,14 wt.%, Ni - 1,06 wt.%, Ti - 0,03 wt.%, Al - remainder. As a result six kinds of composites were obtained (Table 1).

A pressure-vacuum infiltration (DP) was carried out on the Degussa press (T = 720 ºC, p = 15 MPa, t = 15 min). First ceramic perform and metal were located in graphite mould. When the metal was melt, stamp forced liquid aluminum alloy through nozzle to the place, where ceramic preform was located. The graphite stamp exert pressure on liquid metal and 15 MPa pressure was obtained. After the process of the infiltration is completed, the composite was cooled together with the graphite mould in the chamber of the working press. As distinct from the DP method, filling ceramic forms with liquid metal was caused by the gas pressure in GPI infiltration. The gas exert pressure on the surface of metal and it results in penetrating of metal into the pores of ceramic preform. The autoclave stand allows to obtain pressure of 4 MPa the gas at the time of immersion the mould in the liquid metal. The essence of the proposed

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Table 1 **Designation of ceramic-metal composites**

Designation of Al_2O_3/ AK12 composites	Pore size of Al_2O_3 preforms	Designation of ceramic preforms
Infiltration on Degussa Press		
Al_2O_3_1/AK12-DP	300 – 450 µm	Al_2O_3_1
Al_2O_3_2/AK12-DP	400 – 550 µm	Al_2O_3_2
Al_2O_3_3/AK12-DP	800 – 1000 µm	Al_2O_3_3
Gas-pressure infiltration GPI		
Al_2O_3_1/AK12-GPI	300 – 450 µm	Al_2O_3_1
Al_2O_3_2/AK12-GPI	400 – 550 µm	Al_2O_3_2
Al_2O_3_3/AK12-GPI	800 – 1000 µm	Al_2O_3_3

design solution of the autoclave used in the process of GPI is to reduce the contact time of molten metal with reinforcing phase and shortening the cooling time of the composite material outside the heating chamber.

The microstructure of ceramic preforms and ceramic-metal composites was also characterized using X-ray tomography type SkyScan 1 174. Brinell hardness tests were performed too. Furthermore, compression tests were carried out using a Zwick 250 machine with application of Digital Image Correlation (DIC) method. The DIC method was utilized to determine Young's modulus.

RESULTS

The images of the porous Al_2O_3 ceramics obtained using X-ray tomography and distribution of size of the pores was shown in Figures 1 and 2. The Al_2O_3_3 preform is characterized by the biggest pores size. The volume fraction of the ceramics phase is approximately 28 vol.%, the remaining area (72 vol.%) can be filled up with liquid metal (Table 2). The results of X-ray tomography proved very good infiltration of the pores by the metal. The composites obtained from preforms with the smallest pores exhibit the smallest residual porosity (<1 vol.%). Application a gas-pressure infiltration as a fabrication method of composites resulted in the smaller degree of residual porosity (Table 3).

The SEM observations of the composites revealed the percolation type of the microstructure. Moreover, all the pores are fully filled by the aluminum alloy. Only small unfilled voids in the microstructure of the composite obtained by infiltration of the preform was observed (Figure 3).

The effect of the method of the infiltration of Al_2O_3 porous ceramics by AlSi12CuMgNi aluminium alloy on composite compressive strength, hardness and Young's modulus are shown in Figure 4. It was found that compressive strength, hardness and Young's modulus are higher for composites obtained by the gas-pressure infiltration (GPI) of the ceramic performs with the smallest size of pores. The most sensitive property on the method of composite fabrication seems to be compressive strength.

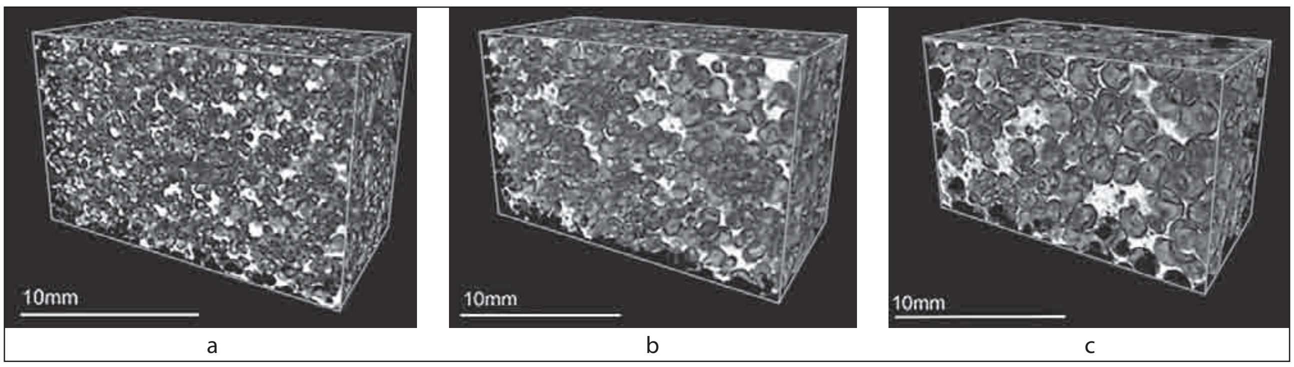

Figure 1 X-ray tomography images of porous Al_2O_3 ceramics: a) Al_2O_3_1 (size of pores 300-450 µm), b) Al_2O_3_2 (size of pores 400-550 µm), c) Al_2O_3_3 (size of pores 800-1000 µm)

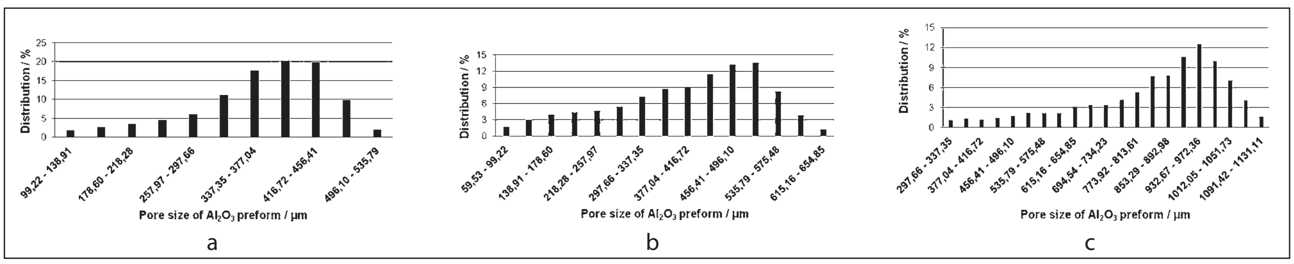

Figure 2 Distribution of pores size of porous ceramics: a) Al_2O_3_1 (size of pores 300-450 µm), b) Al_2O_3_2 (size of pores 400-550µm), c) Al_2O_3_3 (size of pores 800-1000µm)

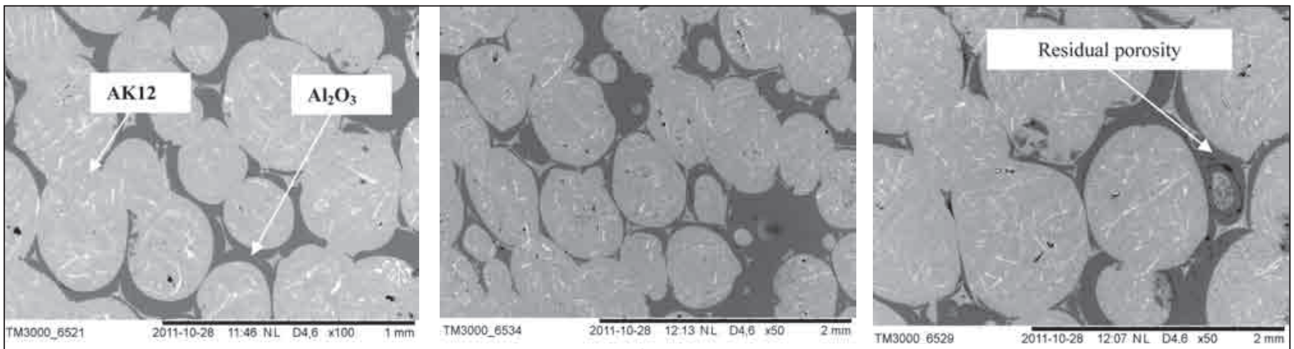

Figure 3 SEM images of Al2O3/AK12 composites: (a) Al2O3_1/AK12, (b) Al2O3_2/AK12, (c) Al2O3_3/AK12

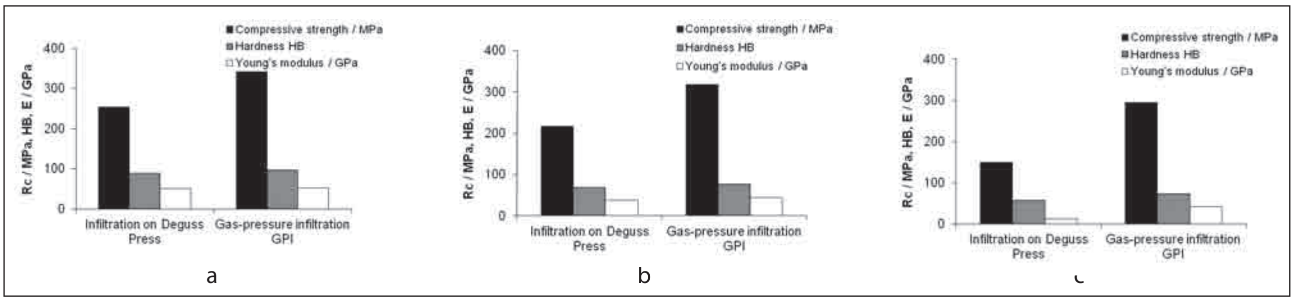

Figure 4 Diagrams of compressive strength, hardness and Young's modulus obtained for composites: a) Al_2O_3_1/AK12, (b) Al_2O_3_2/AK12, (c) Al_2O_3_3/AK12

Table 2 **Volume fraction of Al_2O_3 ceramics perform and pores**

Designation of Al_2O_3 preforms	Volume fraction of Al_2O_3 ceramics / %	Volume fraction of pores / %
Al_2O_3_1	30,57	69,43
Al_2O_3_2	28,52	71,48
Al_2O_3_3	25,58	74,42

Table 3 Degree of infiltration of ceramics by cast aluminum alloy

Designation of Al_2O_3/ AK12 composites	Residual porosity / %	Composite volume / %
Infiltration on Degussa Press		
Al_2O_3_1-DP	0,88	99,12
Al_2O_3_2 -DP	2,45	97,55
Al_2O_3_3 -DP	4,40	95,60
Gas-pressure infiltration GPI		
Al_2O_3_1-GPI	0,57	99,43
Al_2O_3_2-GPI	1,60	98,40
Al_2O_3_3-GPI	1,44	98,56

As shown in Figure 4 the mechanical properties also increased for composites obtained by the gas-pressure infiltration process (GPI) of performs with 400-550 μm and 800 - 1 000 μm pores size.

DISCUSSION

Results of X-ray tomography of ceramic performs prove that volume fraction of Al_2O_3 ceramics and pores are quite the same in all cases. Porosity of ceramic preforms was approximately 30 vol. %. Al_2O_3 preforms differed with pore's size which was changed from 300 μm to 1000 μm. Both of infiltration's methods lead to fabrication of ceramic-metal composites with interpenetrating of phases. These techniques provided also the highest degree of infiltration. It was shown that residual porosity was lower than 5 vol. % for all composites. Comparing results of X-ray tomography and SEM observations for DP and GPI methods it can be considered that gas-pressure infiltration ensures higher degree of infiltration. In this case the amount of not fully filled pores and voids in the microstructure of composites was lower. It was found that both of infiltration methods of ceramic preforms with the smallest size of pores provide better degree of infiltration that infiltration of others preforms. The flow of liquid metal depends on the size of the capillaries, the variation of pressure along the capillary length, the time of preserving the metal in a liquid state within the capillary and on the dynamic viscosity of the alloy.

All types of composites fabricated by the gas-pressure infiltration (GPI) are characterized by higher hardness, compressive strength and Young's modulus. However, the most sensitive property for the method of the composite fabrication, resulted in different residual porosity, seems to be compressive strength. Moreover, the mechanical properties of the composites obtained by the GPI infiltration of the preform with the smallest pores size are higher than for others composites. Hardness, compressive strength and Young's modulus increase together with the increase of the specific surface fraction of the interphase boundaries.

The detailed explanation of these relationships requires further studies which results will be reported in the next publications.

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Note: The responsible translator for English language is P. Nowak, Katowice, Poland