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Aluminium matrix composites fabricated by infiltration method

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ABSTRACT

Purpose: The aim of this work is to examine the structure and properties of metal matrix composites obtained by infiltration method of porous ceramic preforms by liquid aluminium alloy.

Design/methodology/approach: Ceramic preforms were manufactured by the sintering method of ceramic powder. The preform material consists of powder Condea Al_2O_3 CL 2500, however, as the pore forming the carbon fibers Sigrafil C10 M250 UNS were used. Then ceramic preforms were infiltrated with liquid eutectic EN AC – AlSi12 aluminum alloy. Stereological and structure investigations of obtained composite materials were made on light microscope. The mechanical properties of obtained composite material were investigated in tensile strength test and hardness test.

Findings: It was proved that developed technology of manufacturing of composite materials based on the porous ceramic Al_2O_3 preforms infiltrated by liquid aluminium alloy ensures expected structure and strength Hardness increased about twice compared to the matrix and this process can be used in practice.

Practical implications: The presented metal matrix composites fabrication technology allows to obtain locally reinforced elements and near net shape products.

Originality/value: Results show the possibility of obtaining the new aluminium matrix composite materials being the cheaper alternative for other materials based on the ceramic fibers.

Keywords: Composites; Ceramic preforms; Infiltration; Al_2O_3

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MATERIALS

1. Introduction

For many years composite materials have been widened their share on the engineer materials market and what is even more important a demand for them is constantly increasing in quantitatively and qualitative way. Thanks to researches all over the world, the technological difficulties, associated with manufacturing processes, are overcame, particularly for the composite with metal matrix. More over the spectrum of the design rules and the properties improvement of these material group have been bounded.

For the last few years the researches have been led over the composite materials with metallic matrix on the base of light metals and theirs alloys. The researches were devoted to design process as well as manufacturing and special processing of these materials. Currently it is known that composite materials with aluminum matrix enriched with constant strengthening phase are widely used in aeronautics or astronautics (high resistance as well as proper stiffness).

Manufacturing process of the composite materials is connected with high costs and complicated methodology of manufacture [1,3,6,7,12]. According to these problems new researches have been stared to find new manufacturing techniques. It is the reason for examining the composites with aluminium matrix strengthened with Al_2O_3 particles. Manufacturing of these types of composites brings together casting methods as well as powder metallurgy. These modern methods allow to enter new manufacturing ways that enable obtaining composite materials with better values of demanded properties. Manufacturing process simplification impacts on reduction of the costs connected with preparing semi-finished products and production [1,9,10,16].

Taking into the consideration the manufacturing industry one can notice two directions of development of the manufacturing technology of composite materials: powder metallurgy [1,5,6,20] and casting methods - the pressure infiltration of the porous ceramic semimanufactured articles (the preform) with liquid metals alloys.

Currently with these method composite materials with metallic matrix are manufactured. It has response in many scientific papers, it which aim is its improvement and continuous modernization [4,5,13].

The usage of infiltration process as the high-profitable technology is a base of getting the wide range of composite materials and allows to obtaining the following technological-organizational profits [12,14,19]:

- the possibility of obtaining the composite products of precise shape mapping and the high-quality surface (near net shape),
- adaptation of the process to the mass scale production,
- free variability of reinforcing phase and matrix material,
- high-productivity process with relatively low-cost of production,
- the possibility of local reinforcement of the product [5,6].

The ceramic preforms, being a framework, are the base of the composite materials manufactured by infiltration method. These preforms mainly determine the structure and the properties of the final product. The properly manufactured semi-finished product should be characterized by the structure of open joined canals allowing the liquid metal to flow as easily as possible. The occurrence of the closed pores or blind canals causes formation of areas with no metal [3,6,14,15].

Composite materials on the light metals alloys matrix have some specific types which are still in the areas of researches and observations. This type of materials are specially used in aircraft and electric industry and in many others areas. Nowadays engineers use more often composite materials which bring together advantages of components they were made of [1,2,7,18,20].

The aim of this paper is investigation of selected strength properties as well as structure of modern composite materials with matirix of EN AC-AlSi12 alloy manufactured with pressure infiltration of porous ceramic skeletons obtained with method of metallurgy of the powder Al_2O_3 Condea Cl 2500 with the addition of pores and canals structure forming agent in the form of carbon fibres Sigrafil C10 M250 UNS of Company SGL Carbon Group.

2. Experimental procedure

Materials were obtained in the pressure infiltration method with liquid metal alloys EN AC-AlSi12. The chemical composition of the alloy is shown in the Table 1.

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

The base of the composite material manufactured by infiltration method are ceramic performs which should be characterized by open pores structure that enables liquid alloy flow. More over the semi-finished product should have appropriate resistance not to get in strains and cracks during infiltration what could lead to heterogeneity of the structure of the final material [1,5,6,10,15,19].

The obtained ceramic preforms were measured and weighed on the assumption that their composition consists of Al_2O_3 Condea CL 2500 with density 3,98g/cm^3 for a calculation of the amount of ceramic phase fraction and therefore its porosity. The chemical constitution and diemeter of the powder Al_2O_3 Condea CL 2500 are shown in the Table 2.

Table 2.
Chemical composition and particle diameter of Al_2O_3 Condea CL 2500 powder

Diameter D50, μm	Mean mass concentration of elements [wt.%]						
	Al_2O_3	Na_2O	Fe_2O_3	SiO_2	CaO	B_2O_3	Others
1.80	99.80	0.05	0.02	0.01	0.01	0.01	0.10

The ceramic preforms were manufactured by sintering of Al_2O_3 Condea CL 2500 powder with the addition of pores and canals structure forming agent in the form of carbon fibres Sigrafil C10 M250 UNS of Company SGL Carbon Group. The course of sintering process is presented in Fig. 1. The properties of used carbon fibers are shown in Table 3. The addition of the carbon fibers was 30, 40 and 50 % of weight, pressed under pressure of 100 MPa.

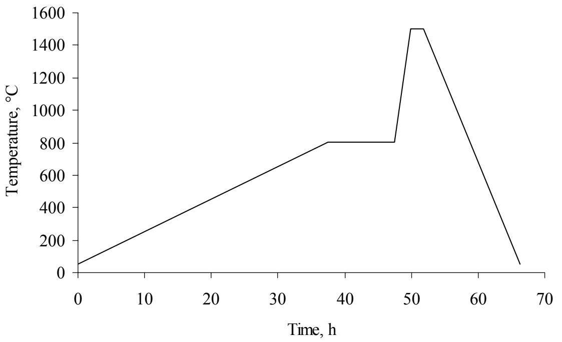


Fig. 1. Temperature performance during the sintering process

Table 3.
Properties of Sigrafil C10 M250 UNS carbon fibers [2]

Fiber diameter µm	Mean fiber length µm	Fiber density g/cm^3	Tensile strength GPa	Youngs modulus GPa	Carbon content %
8	135	1.75	2.5	26	>95

The researches in regards to the mechanical properties were led, i.e. tensile strength test and measurement of hardness and metallographic investigations which contain stereological investigations as well as metallographic microscopic investigations.

Tensile strength test was carried on testing machine company ZWICK/Z100.

The test was carried on specimens obtained from respectively 30, 40, 50% addition of carbon fibers, pressed under the pressure of 100 MPa for 15 s. The specimens were cut appropriately and prepared for investigation (Fig. 2). The dimensions of these specimens are not normalized because the overall dimensions of the material from which they were obtained were too small – they were discs with diameter of 30 mm.

The test was carried out according to the standard PN-EN 10002-1:2004. During the test on testing machine the graph of stretching tension – extension was recorded and tensile strength was determined.

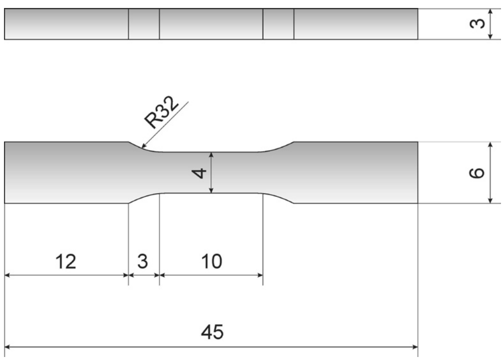


Fig. 2. Scheme of the specimen prepared for the tensile strength test (dimension in mm)

The basis for determining hardness with this method is measure of the permanent (permanent depth increase of the imprint h) after removing the basis load, but with initial load. The results are in HRA units on adequately scaled sensor.

The test was led for three specimens on the basis of perform obtained from respectively 30, 40, 50% addition of carbon fibers pressed under the pressure of 100 MPa for 15 s and one specimen of the matrix material. The specimens were prepared in the way which provides smooth, flat, regular surfaces and without any contaminations and foreign bodies where the measure was taken.

Hardness was measured in ten separate places (for every specimen) and the average value was determined. The test was taken out according to the standard PN – EN ISO 14577–1;2003.

The investigation of the volume share of the ceramic phase was carried out with computer application LEICA QWin which analyses the images. It cooperates with metallurgical microscope Axiovert 405M produced by OPTON. The image is observed on the camera JVC TK type – C1381EG, and then transmitted to the computer where it is analyzed with application mentioned above.

The aim of that test was to compare volume share of the ceramic phase determined with evaluations and the one that was obtained during experimental investigation. The test was led for three specimens on the basis of performs obtained from respectively 30, 40, 50% addition of carbon fibers pressed under the pressure of 100 MPa for 15 s.

To determine the theoretical volume share of the ceramic phase the dimension and the mass of the preforms need to be known.

To determine the theoretical volume share of the ceramic phase the dimension and the mass of the performs need to be known as well as material used – in this particular case the density of the Condea Cl 2500 powder is equal 3.98 [g/cm^3].

When we have gathered values mentioned above we are able to evaluate what would be the volume of the solid material without the pores. To do that we use the equation:

$$V = \frac{m}{\rho} \qquad (1)$$

where:
V – volume [cm^3]
m – mass[g]
ρ – density [g/cm^3]

In the next step the real volume of given perform is divided by the volume obtained in the previous step and multiplied by 100%. In this way the volume share of the ceramic phase is determined. Metallographic observations of the composite materials with a diversificated volume of the ceramic phase were carried out on the light microscope MEF4A type Leica with a magnification 100-1000x.

Metallographic specimens were not etched to observe the structure (ceramic phase distribution in the metal matrix) and the infiltration degree.

Fractographic examinations of obtained composite materials were made on the Zeiss Supra 40 scanning electron microscope.

3. Results and discussion

The results of the tensile strength test carried out on testing machine ZWICK/Z100 are presented in Table 4 and the graphic mapping is shown in Fig.3.

Table 4.
Tensile strength and hardness of obtained composite materials with different ceramic fraction

Properties	Matrix	Composite material with different volume fraction of ceramic phase		
		18.80%	24.30%	29.50
Hardness HRA	21.80	37.73	45.84	51.01
Strength, MPa	201.46	219.86	276.99	301.47

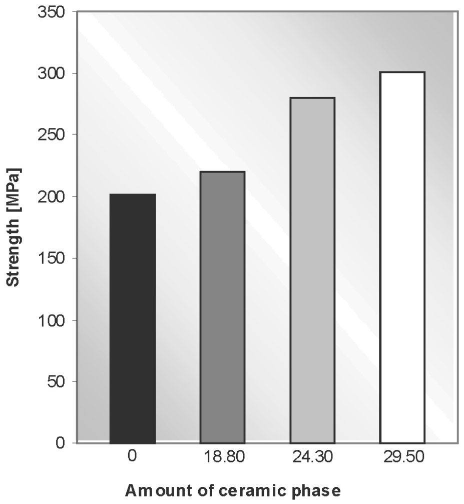


Fig. 3. Tensile strength of obtained materials versus ceramic phase fraction

On the basis of carried out experiments obtained composite materials one can conclude that with increasing the strengthening particles (ceramic phase) impedes the deformity engineering materials and increase its resistance.

Investigated material did not deform plastically dry. On the basis of the test led on hardness measuring instruments ZWICK/ZHR obtained composite material one can notice that hardness significantly increased in comparison to the matrix material EN AC-AlSi12.

More over one can observe increase of the investigated material hardness in regards to the increasing the volume share of the ceramic phase.

The results are shown in Table 4 and the graphic interpretation is presented in Fig. 4.

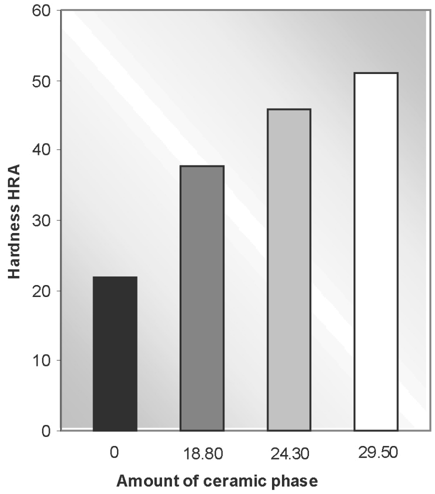


Fig. 4. Hardness of obtained materials versus fraction of the reinforcement

Geometry and quantity measurements as well as sterological researches of the ceramic preforms manufactured by powder sintering with the 30, 40 and 50% volume fraction of the carbon fibers enabled to determine the volume fraction of the ceramic phase of the pore material, what is shown in the Table 5. The graphic interpretation is shown in the Figure 5.

Table 5.
Ceramic phase volume fraction in performs obtained from powders with different carbon fibers addition

Carbon fibers content [wt.%]	Volume ceramic phase fraction [%]	Surface ceramic phase fraction [%]
30	29.50	31.70
40	24.30	25.25
50	18.80	21.05

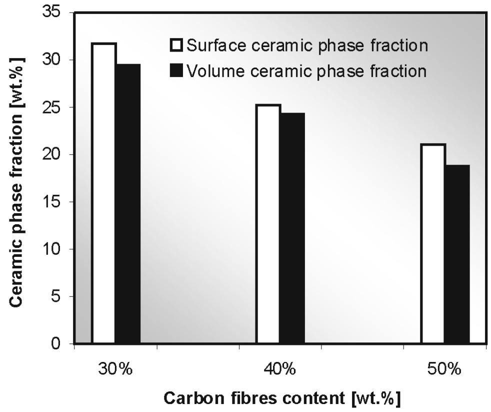
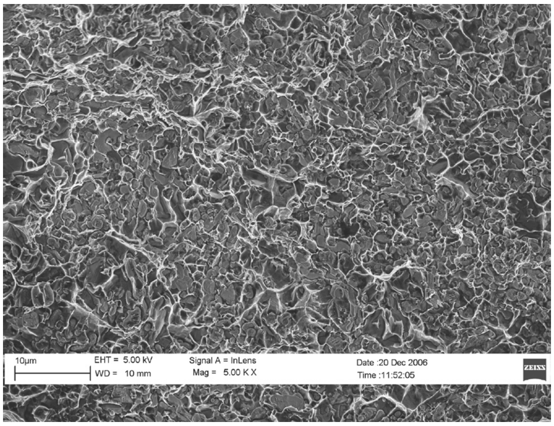
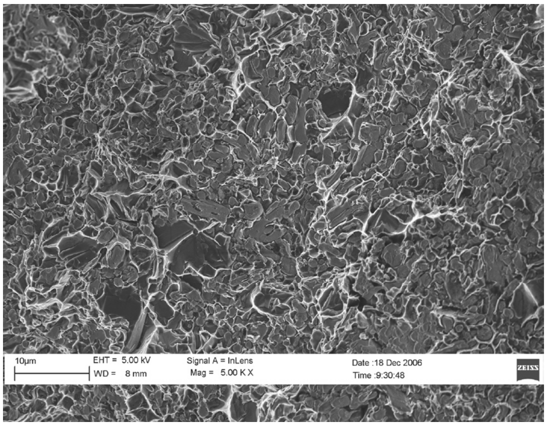


Fig. 5. Comparison of volume fraction and surface fraction of ceramic phase in preforms obtained from powders with different carbon fibers addition

a)



b)



c)

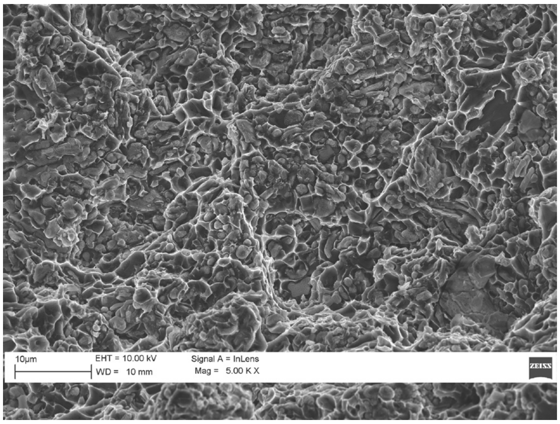


Fig. 6. Microstructure of fracture of obtained composite material with different portion of ceramic phase: a) 29.50%; b) 24.30%; c) 18.80%

The difference between the surface volume of the ceramic phase obtained in the stereological investigations and the volume fraction on the assumption that the particles are uniformly placed and chaotically overlapped can interpret as difficulties result of the program image analysis calibration. Small pores around the ceramic particles weren't identified as matrix, but as reinforcement phase what is a prove that its volume is bigger than the calculation points [2,3,4,12].

Fractographic examinations of fractures of the composite material obtained by infiltration of the porous ceramics reveal that the liquid aluminium alloy fills the micro-pores entirely around the Al_2O_3 particles. The observed images are shown in Fig. 6.

The results of the metallographic investigation of the composites materials on the base of the pore ceramic obtained by infiltration of aluminum alloy are showed in Figures 7 a-f. The observations enabled to state uniform distribution of the ceramic phase in the metal matrix. Additionally the decrease of ceramic phase occurrence with the increase of the carbon fibers amount in composites materials can be seen (Figs. 7 a-c).

On the basis of the pictures taken by bigger magnification (Figs. 7 d-f) we were able to state that the infiltration process was completed. All pores and crevices were fulfilled with liquid material of the matrix (aluminium alloy EN AC-AlSi12), additionally it can by noticed that even microspores formed at the border of the ceramic particles under the influence of pressure occurring during the infiltration process are fulfill tightly.

More over it is necessary to mention that sections of the samples observed on the metallographic microscope are parallel to the acting direction of the applied force during the compacting process. Because of that in the pictures circle pores can be seen more often than oblong grooves reflecting fibers cross-section. They reflect the diameter of the carbon fibers formed in the place of the burning process. It proves that carbon fibers during the compacting process are more likely to be set in the perpendicular to the direction of the compacting forces acting.

4. Conclusions

On the base of investigation carried out it can be shown that the hardness of obtained composite materials significantly increase in regards to the matrix material. The growth is proportional to the portion of ceramic phase in the material. There was also found the dependance between composite materials strenght and the volume fraction of ceramic phase in preforms. The values obtained during these tests enables to conclude that increase of the ceramic particles fraction impedes the deformation of the composite materials.

Presented calculations and stereological measurements show that there is a possibility to manufacture by proposed method composite materials with the volume of ceramic phase in the range of 18.80-29.50%. The metallographic observations of composite material manufactured by infiltration of ceramic structures with liquid aluminium EN AC-AlSi12 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 micropores created between ceramic particles and crevices are fulfilled with liquid matrix material. It was proved that developed technology of manufacturing provides apropperiate structure composite materials and can be applied in practice.

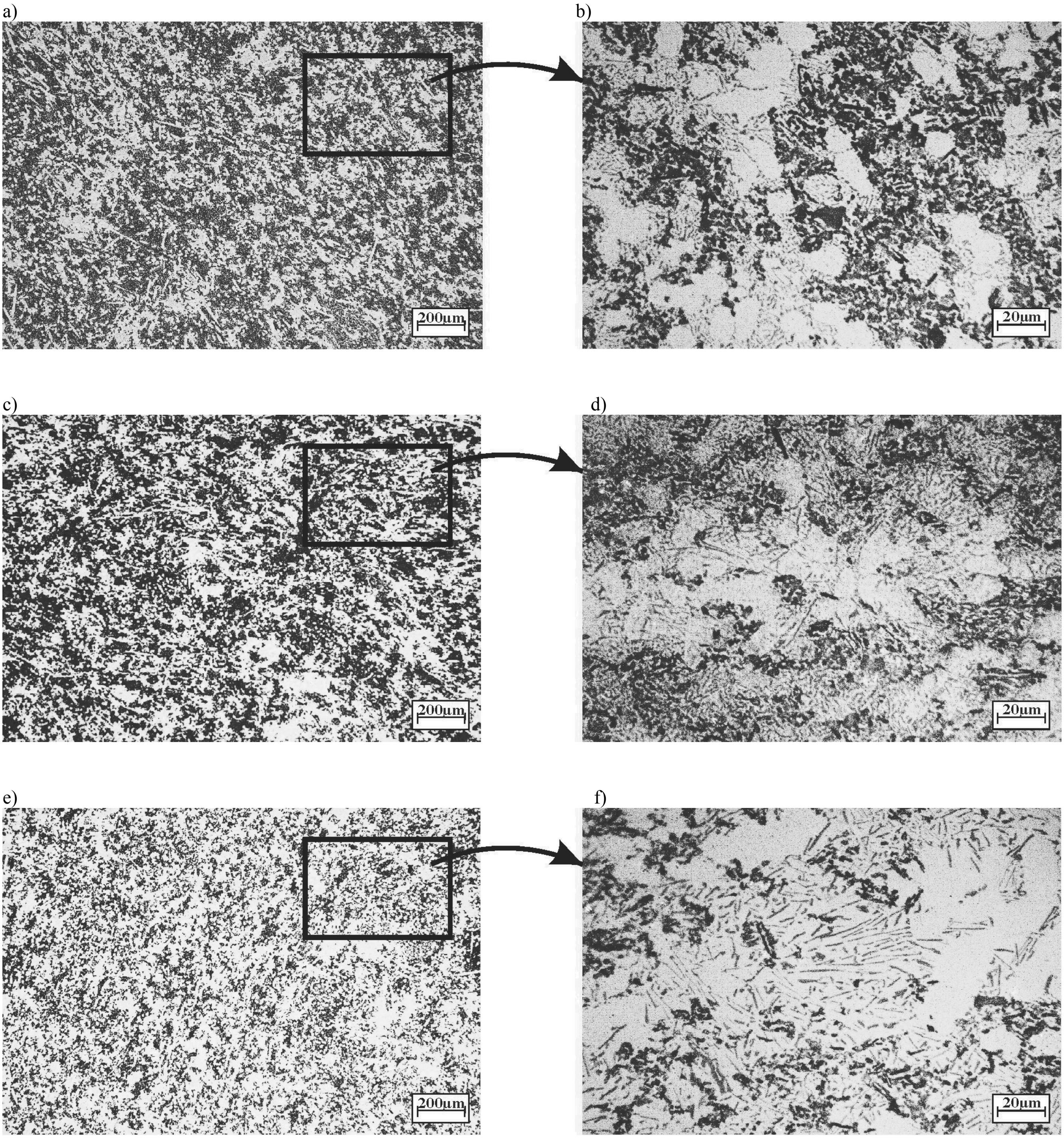


Fig. 7. Structure of not etched composite materials with aluminium matrix reinforced by different amount of ceramic phase: a, b) 29.50%; c, d) 24.30%; e, f) 18.80%

Results mentioned above confirm the possibility of obtaining the pressure infiltration of the porous, ceramic preforms with liquid alluminium alloys new materials with properties that bring together advantages of the material components. More over they are cheaper alternative for widely used composite materials with matrix built of light alloys reinforced with ceramic on the basis of fibers.

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References

[1] A. Włodarczyk-Fligier, L.A. Dobrzański, M. Kremzer, M. Adamiak, Manufacturing of aluminium matrix composite materials reinforced by Al_2O_3 particles, Journal of Achievements in Materials and Manufacturing Engineering 27/1 (2008) 99-102.

[2] L.A. Dobrzański, M. Kremzer, M. Drak, Moder composite materials manufactured by pressure infiltration method, Journal of Achievements in Materials and Manufacturing Engineering 30/2 (2008) 121-128.

[3] L.A. Dobrzański, M. Kremzer, J. Trzaska, A. Włodarczyk-Fligier, Neural network application in simulations of composites Al-Al_2O_3 tribological properties, Archives of Material Science and Engineering 30/1 (2008) 37-40.

[4] L.A. Dobrzański, M. Kremzer, A. Nagel, Application of pressure infiltration to the manufacturing of aluminium matrix composite materials with different reinforcement shape, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 183-186.

[5] L.A. Dobrzański, M. Kremzer, A. Nagel, Aluminium EN AC – AlSi12 alloy matrix composite materials reinforced by Al_2O_3 porous performs, Archives of Materials Science and Engineering 28/10 (2007) 593-596.

[6] V.M. Kevorkijan, The reactive infiltration of porous ceramic media by a molten aluminum alloy, Composites Science and Technology 59 (1999) 683-686.

[7] W.S. Sheng, S.J. Lin, Ni-coated SiC_p reinforced aluminum composites processed by vacuum infiltration, Materials Research Bulletin 31/12 (1996) 1437-1447.

[8] G.W. Han, D. Feng, M. Yin, W.J. Ye, Ceramic/aluminum co-continuous composite synthesized by reaction accelerated melt infiltration, Materials Science and Engineering A225 (1997) 204-207.

[9] Abd-Elwahed M. Assar, Fabrication of metal matrix composite by infiltration process-part 2: experimental study, Journal of Materials Processing Technology 86 (1999) 152-158.

[10] N. Nagendra, B.S. Rao, V. Jayaram, Microstructures and properties of Al_2O_3/Al-AlN composites by pressurless infiltration of Al-alloys, Materials Science and Engineering A269 (1999) 26-37.

[11] M. Szafran, G. Rokicki, W. Lipiec, K. Konopka, K. Kurzydłowski, Porous ceramic infiltrated by metals and polymers, Composites 2 (2002) 313-316 (in Polish).

[12] J. Sobczak, Metal Composites, Foundry Institute - Motor Transport Institute Publishers, Cracow–Warsaw, 2001 (in Polish).

[13] 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.

[14] G.G. Kang, Y.H. Seo, The influence of fabrication parameters on the deformation behavior of the perform of metal-matrix composites during the squeeze-casting processes, Journal of Materials Processing Technology 61 (1996) 241-249.

[15] K. Naplocha, A. Janus, J.W. Kaczmar, Z. Samsonowicz, Technology and mechanical properties of ceramic performs for composite materials, Journal of Materials Processing Technology 106 (2000) 119-122.

[16] 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.

[17] M.P. Dariel, L. Levin, N. Frage, Graded ceramic performs: various processingapproaches, Materials Chemistry and Physics 67 (2001) 192-198.

[18] N. Altinkok, A. Demir, I. Ozsert, Processing of Al_2O_3/SiC ceramic cake performs and their liquid metal infiltration, Composites 34 (2003) 577-582.

[19] L.A. Dobrzański, M. Kremzer, A.J. Nowak, A. Nagel, Composite materials based on porous ceramic preforms infiltrated by aluminium alloy, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 95-98.

[20] A. Dolata-Grosz, J. Wieczorek, Tribological properties of hybryd composites containing two carbide phases, Archives of Materials Science and Engineering 28/3 (2007) 149-155.