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Composite materials based on porous ceramic preform infiltrated by aluminium alloy

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ABSTRACT

Purpose: The goal of this project is the optimization of manufacturing technology of the ceramic preforms based on Al_2O_3 powder manufactured by the pressure infiltration method with liquid metal alloy.
Design/methodology/approach: Ceramic preforms were manufactured by the method of sintering of ceramic powder. The preform material consists of powder Condea Al_2O_3 CL 2500, however, as the forming factor of the structure of canals and pores inside the ceramic agglomerated framework the carbon fibers Sigrafil C10 M250 UNS were used. Then ceramic preforms were infiltrated with liquid EN AC – AlSi12 aluminum alloy. Stereological and structure investigations of obtained composite materials were made on light microscope.
Findings: It was proved that developed technology of manufacturing of composite materials with the pore ceramic Al_2O_3 infiltration ensures expected structure and can be used in practice.
Practical implications: The developed technology allows to obtain method's elements locally reinforced and composite materials with precise shape mapping.
Originality/value: The received results show the possibility of obtaining the new composite materials being the cheaper alternative for other materials based on the ceramic fibers.
Keywords: Composites; Ceramic preforms; Infiltration, Al_2O_3

1. Introduction

For the past few years successive growth of the interests in the material composites can be noticed. This progress is determined by increasing demeans of the users versus quality and exploitative of the engineering materials. Special attention is given to the metal composites reinforced by the ceramic particles. These materials have very good mechanical properties, stiffness and wear resistance by relatively low density as well as smallest coefficient of the thermal expansion in proportion to the matrix. [1,2,4,6]. With regard to their advantages, they have been widely used in motorization, air industry and also to produce sport equipment. Composite materials on the matrix of light metal alloys can be produced elements exposed to the impact of high temperature, elements subjected to intensive wear and also elements in power transmission systems with low friction coefficient and high vibration damping capability [1, 5, 6].

Two main directions of development of metal composite materials manufacturing technology are observed: powder metallurgy [1-3] and casting methods, with specific modification of the pressure infiltration of the porous, ceramic preforms with liquid metals alloys. This method is used more and more often in manufacturing of the composite materials with metal matrix and has also become the subject of many research projects [4-11]. The usage of infiltration process as the high-profitable technology is a base of the wide range of composite materials and allows to gain obtaining the following technological-organizational profits [12]:

- 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 the 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 more often use composite materials which bring together advantages of components they were made of. [1, 2, 7].

The aim of this paper is to study the structure of the composite materials with the EN AC-AlSi12 matrix manufactured by pressure infiltration of pore ceramic structures obtained by sintering of powder Al_2O_3 Condea CL 2500 with the addition as pores and canals structure forming agent. Carbon fibres Sigrafil C10 M250 UNS of Company SGL Carbon Group.

2. Experimental procedure

Material was 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.

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].

The ceramic preforms were manufactured by sintering of 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. The properties of the used carbon fibers were shown in Table 2. The addition of the carbon fibers was 30, 40 and 50 % of weight, pressed under pressure of 100MPa.

The obtained ceramic preforms were measured and weighted what 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.

Stereological investigations were carried out on the light microscope Axiovert 405M Option equipped with the camera JVC TK-C1381EG and the application of Leica Qwin computer program used for image analysis. The aim of this tests was to compare the surface volume of the ceramic phase with the volume fraction determined with the weight and geometry measurements of the performs. The test was carry out for three samples on the basis of performs with corresponding 30, 40, 50% volume of the carbon fibers [8, 9, 11].

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 etching to observe the structure (ceramic phase distribution in the metal matrix) and the infiltration degree.

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

Mean mass concentration of elements [wt.%]								
Si	Cu	Mg	Mn	Pe	Ti	Zn	Ni	Pb
12	≤0,15	≤0,1	≤0,55	≤0,65	≤0,2	≤0,15	≤0,1	≤0,1

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

Properties	
Fiber diameter [μm]	8
Mean fiber length [μm]	135
Fiber density [g/cm^3]	1,75
Tensile strength [GPa]	2,5
Young's modulus [GPa]	26
Carbon content [%]	>95

3. Results and discussion

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 3. The graphic interpretation is shown in the Figure 1.

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 the as a 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].

Table 3.
Ceramic phase volume fraction in performs obtained from powders with different amount of carbon fibers addition [5]

Carbon fibers content [wt.%]	Volumetric amount of ceramic phase fraction [wt.%]	The surface amount of ceramic phase fraction [wt.%]
30	29,46	31,70
40	24,30	25,25
50	18,77	21,04

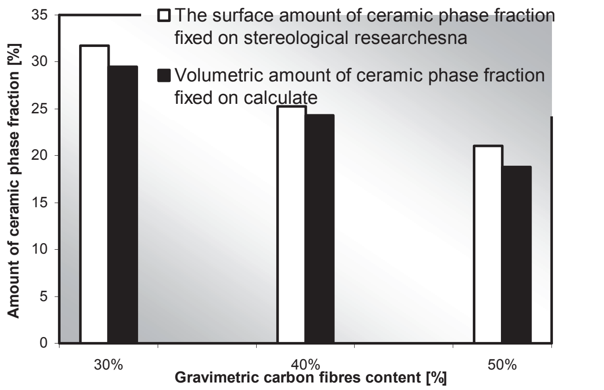

Fig. 1. The amount ceramic phase versus carbon fibers content

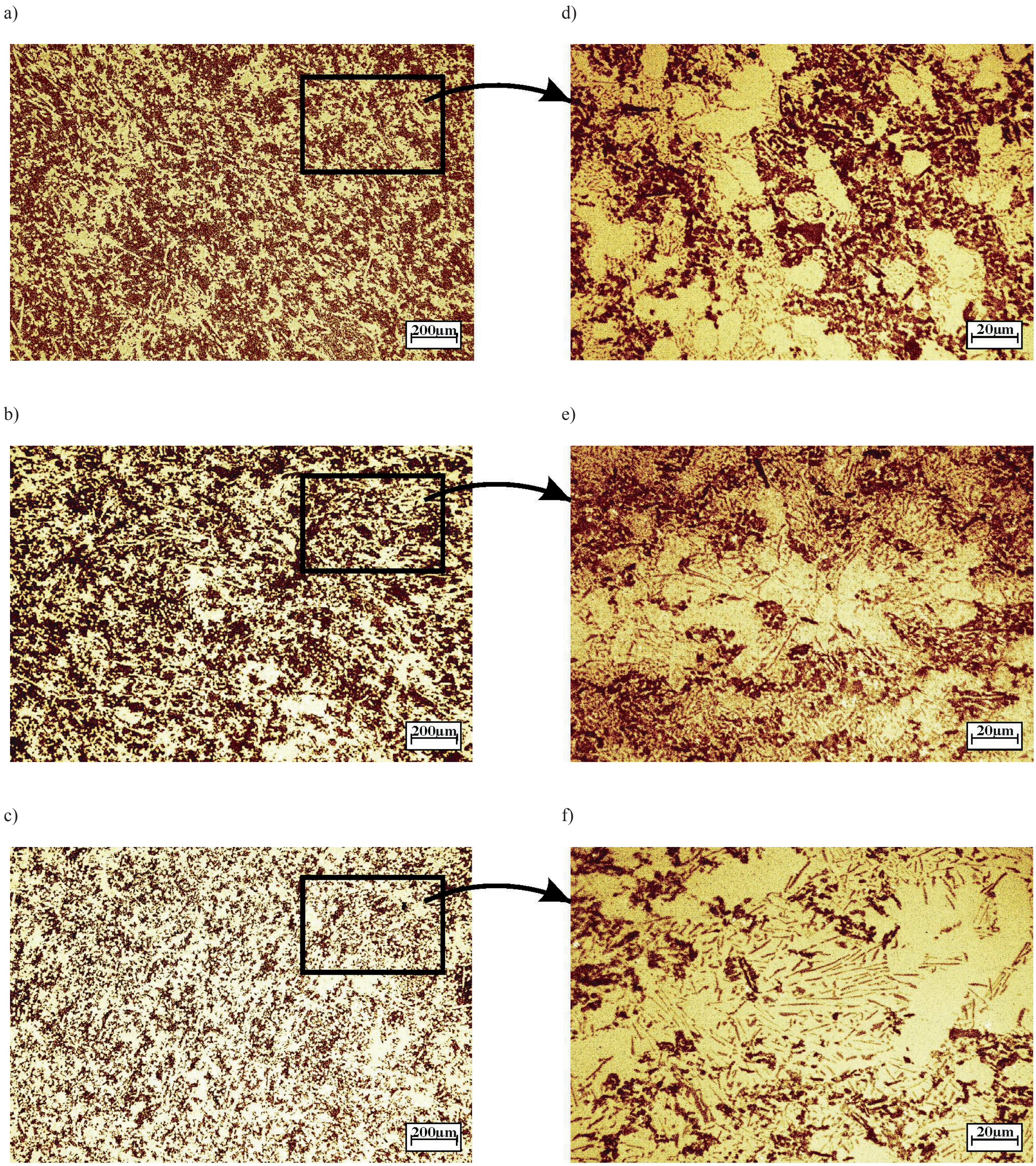

Fig. 2. Structure of not etched composite materials with ceramic matrix reinforced by aluminum alloy with difrent amount of ceramic phase: magnification (100x) a) 29.50%; b.) 24.30%; c) 18.80% phase, magnification (1000x) d) 29.50%; e) 24.30%; f) 18.80% phase

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 the Figure 2 a-f. The observations enabled to state uniform distribution of the ceramic phase in the metal matrix. Additionally can by seen the decrease of ceramic phase occurance with the increase of the carbon fibers amount in composites materials (Fig. 2 a-c).

On the basis of the pictures taken by the bigger magnification (Fig. 2 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 notice 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 it can by seen circle pores 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

Geometrical and quantity stereological measurements shows that there is a possibility to manufacture by proposed method composite materials with the volume of ceramic phase in the range of 20-30%.

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 conclude that if the process of infiltration was complete, all pores (microspores created between ceramic particles and crevices are fulfill with liquid matrix material). It was proved that developed technology of manufacturing provides apropperiate structure composite materials and can be applied in practice.

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