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Aluminium EN AC – AlSi12 alloy matrix composite materials reinforced by Al_2O_3 porous preforms

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ABSTRACT

Purpose: The purpose of this work is to elaborate the method of manufacturing of composite materials based on porous ceramic preforms infiltrated by eutectic aluminium alloy.

Design/methodology/approach: The material for investigations was fabricated by pressure infiltration method of ceramic porous preforms. The eutectic aluminium alloy EN AC – AlSi12 was use as a matrix while as reinforcement were used ceramic preforms fabricated by sintering of Al_2O_3 Alcoa CL 2500 powder with addition of pore forming agents as carbon fibres Sigrafil C10 M250 UNS manufactured by SGL Carbon Group company. The observations of the structure were made on the light microscope and in the scanning electron microscope. EDS and XRD analysis of obtained composite materials have been also made.

Findings: The 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 composite materials made by the developed method can find application as the alternative material for elements fabricated from light metal matrix composite material reinforced with ceramic fibrous preforms.

Originality/value: The obtained results show the possibility of manufacturing the composite materials by the pressure infiltration method of porous sintered framework based on the ceramic particles with liquid aluminium alloy.

Keywords: Composites; Ceramic preforms; Infiltration

MATERIALS

1. Introduction

Advanced light metal matrix composites have a potential for application as engineering materials in energy technology and in mobile or aircraft industry because of their low density, low cost and ease of fabrication. In recent years, much interest was focused on the use of Al_2O_3 fibres or particles reinforced aluminium matrix composite materials. The process for obtaining these composites include solid-state processes such as powder metallurgy (PM) [1-4], where metal and ceramic powders are blended and hot-pressed, and liquid-state processes such as melt infiltration, blending ceramic powder and molten aluminium and casting, melt stirring, pressurized infiltration and squeeze casting [5-10].

The infiltration of ceramic porous preform by a liquid alloy is a cost-effective method for the manufacture of metal matrix composites. Traditionally, the continuous phase of the composite has been designed as the matrix. More recently, interest has arisen in composites where both phases are continuous, resulting in an interpenetrating microstructure. One method to achieve such a microstructure is the infiltration of molten metal into a porous ceramic body called a preform [5]. Producing the composite materials by the method of pressure infiltration of porous ceramic frameworks brings many advantages in which it is 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 [11].

Taking advantage of the properties of aluminium as a matrix and ceramic fibres as reinforcement in the composite material is dependant on the metal-ceramics joint structure developed in the technological process. Unfortunately, the wettability of ceramic particles with liquid aluminium alloys is generally poor and makes impossible spontaneous infiltration of a liquid into a porous solid medium which takes place only when liquid wets the solid. Otherwise to infiltrate the ceramic preform external pressure should be applied [12]. This pressure is limited by the mechanical strength of the ceramic sample [13]. Various technological operations have been recommended to improve the wetting of ceramic by liquid metal, and include increasing metal liquid temperature, pretreatment of ceramic particles or fibres, coating or the ceramics, and adding some surface-active elements into the matrix. One of the conceptions of coatings, advised in the literature most often, is applying the Ni-P coatings onto Al_2O_3 [14, 15].

The goal of this work is the development of the manufacturing technology of the EN AC - AlSi12 alloy matrix composite material reinforced with the Al_2O_3 preforms fabricated by sintering of Alcoa CL 2500 powder with addition of pore forming agent, employing the method of infiltrating the porous ceramics with the liquid metal.

2. Experimental procedure

The material for investigation was produced by pressure infiltration method of porous ceramic preforms with liquid aluminium alloy. The EN AC - AlSi12 alloy features the matrix material, whose chemical composition is presented in Table 1 and as the reinforcement the porous ceramic performs consisted of sintered Al_2O_3 particles were used.

Porous ceramic performs were produced by sintering method of Aloca CL 2500 Al_2O_3 powder 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 2. Manufacturing process of the ceramic preforms included:

- preparation of powder and carbon fibres mixture,
- pressing of prepared powder mixture
- compact sintering.

Table 1.
Chemical composition of EN AC-AlSi12 aluminium alloy .

Mean mass concentration of elements, wt.%							
Si	Fe	Cu	Mn	Zn	Ti	Others	Al
12	≤0.55	≤0.05	≤0.35	≤0.15	≤0.2	≤0.15	The others

The addition of the carbon fibres was 30, 40 and 50 % of weight. In order to make pressing easier, 1% polyvinyl alcohol Moviol 18-8 solvable in water was added. The ceramic powder and carbon fibres mixtures were uniaxially pressed in the hydraulic press “Nelke” in steel mold with the inside diameter of 30mm. The maximum pressure was 100MPa and pressing time was 15s. Compacts 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 porosity of the ceramic performs depends on the carbon fibres content and is a part of 68.80% at 30% of carbon fibres addition, 75.60% at 40% of carbon fibres addition and 80.80% at 50% of carbon fibres addition. The internal surfaces of ceramic preforms were coated with nickel in order to improve the Al_2O_3 wettability by the liquid aluminium alloy. Solutions containing metallic palladium were used for activation of the ceramics surface. Reagents were pumped through preforms to cover their internal surfaces on especially designed device.

Prepared ceramic 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. The maximum infiltration pressure was 100 MPa and and its influence was 120 s. After solidification obtained materials ware removed from the form and cool down under pressured air stream.

The observation of the structure of Ni-P coated ceramic preforms fractures, manufactured by the sintering of Al_2O_3 Alcoa CL 2500 powder method was carried out using the Zeiss Supra 25 scanning electron microscope equipped with EDS device.

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 LEICA MEF4A and in the scanning electron microscope Zeiss Supra 25 equipped with EDS device.

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	The others
1.80	3.98	99.80	0.05	0.02	0.01	0.01	0.01	0.10

Phase composition of the investigated material was determined using the DRON 2 diffractometer with the step data logging, employing the filtered Kα-X-ray radiation of the λ = 1,79021 nm wavelength obtained from a cobalt lamp powered with the 40 kV voltage at the 8 mA heater current. The measurements were made in the angle range 2θ from 30 to 105º.

3. Experimental results and their discussion

The preform's morphology observed on the scanning electron microscope is presented in Figure 1. The blank is characteristic of the homogeneous distribution of sintered Al_2O_2 particles. The nickel coating of the continuous nature can be observed on the entire Al_2O_3 ceramics surface, that was also confirmed by EDS investigations (Fig. 2).

Results of metallographic examinations of the composite materials obtained by infiltration of porous ceramic preforms with the EN AC – AlSi12 alloy, carried out on the light microscope are presented in Fig. 3. The observations enabled to state uniform distribution of the ceramic phase in the metal matrix. Investigation did not confirmed the presence of Ni-P layer on the surfach of Al_2O_3 phase because it's thickness is too small to be obserwed on light microscope.

Results of the quantitative micro-analysis made with X-ray dispersive radiation of composite material obtained by infiltration of ceramic performs show the presence of aluminum and silicon representing a matrix alloy and Al_2O_3 representing reinforcing phase (Fig. 4).

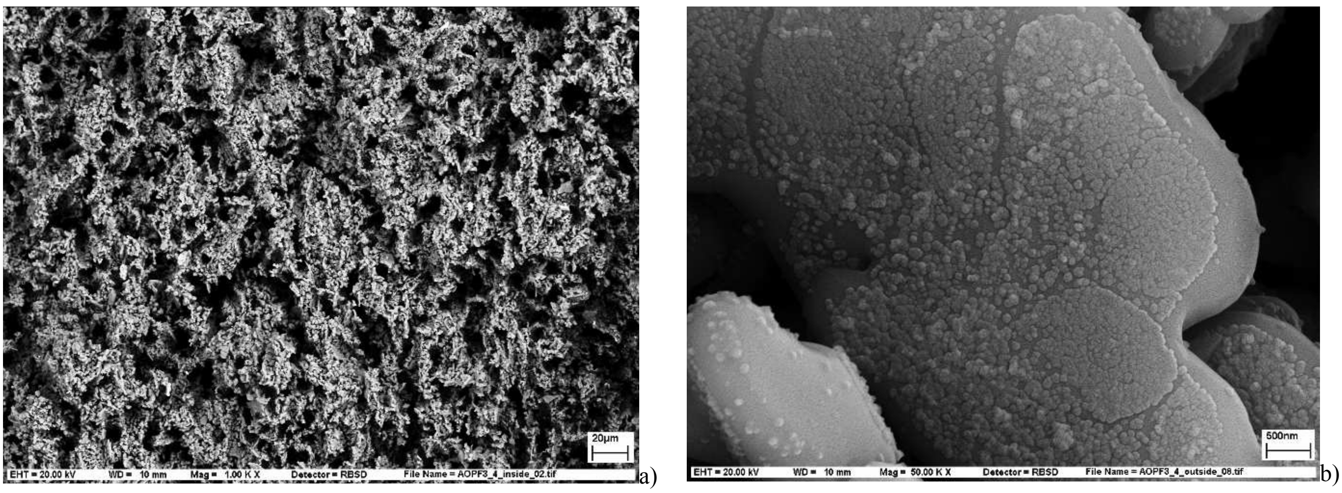

Fig. 1. The microstructure of Ni-P coated ceramic preforms: a) fracture, b) singular grain with Ni-P layer

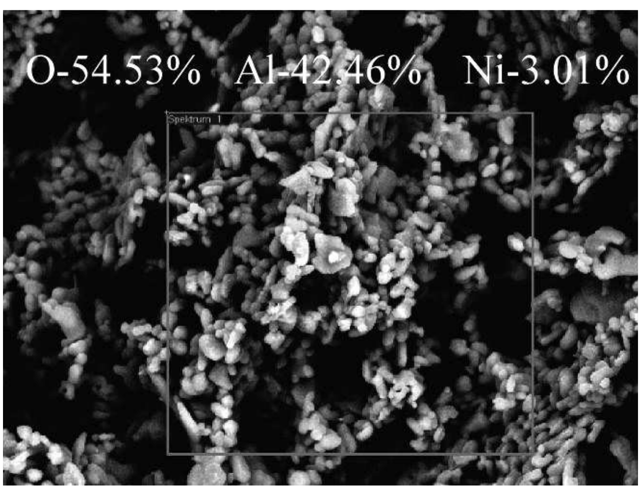

Fig. 2. Results of EDS analysis of Al_2O_3 preform after covering by nickel layer

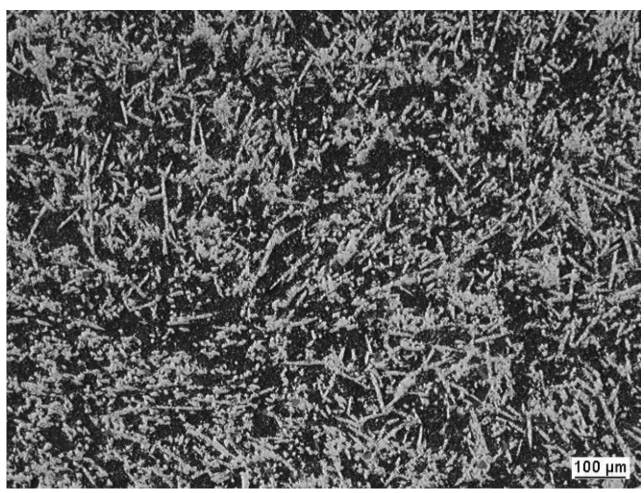

Fig. 3. Structure of the composite material with the aluminium alloy matrix reinforced with the Al_2O_3 porous preform

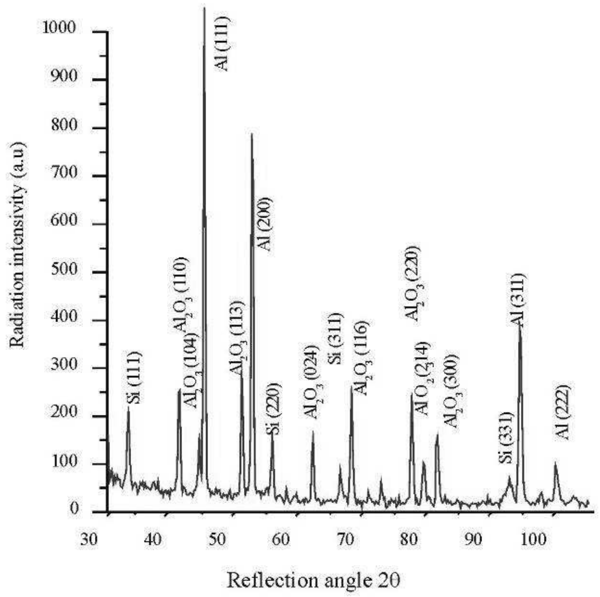

Fig. 4. X-Ray diffraction pattern of obtained composite materials

4. Conclusions

The preform observations shown homogeneous distribution of sintered Al_2O_2 particles and the deposited nickel layer have continuous nature. 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.

It was found out that the developed technology of fabrication the composite material with the EN AC – AlSi12 alloy matrix reinforced with the Al_2O_3 frameworks, consisting in the infiltration of obtained ceramic preforms with the liquid aluminum alloy makes a possibility of obtaining new materials with all advantageous properties of the particular composite.

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