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Manufacturing of aluminium matrix composite materials reinforced by Al_2O_3 particles

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ABSTRACT

Purpose: The purpose of the paper is to show and compare of modern method composite materials with aluminium alloy matrix reinforced by Al_2O_3 particles manufacturing.

Design/methodology/approach: Material for investigation was manufactured by two methods: powder metallurgy (consolidation, pressing, hot extrusion of powder mixtures of aluminium EN AW-AlCu4Mg1(A) and ceramic particles Al_2O_3) and pressure infiltration of porous performs by liquid alloy EN AC AlSi12 (performs were prepared by sintering of Al_2O_3 powder with addition of pores forming agent – carbon fibers).

Findings: The received results show the possibility of obtaining the new composite materials with required structure joining positive properties composite materials components.

Practical implications: Tested composite materials can be applicate among the others in automotive industry but it requires additional researches.

Originality/value: Worked out technologies of composite materials manufacturing can be used in the production of small elements near net shape and locally reinforced elements.

Keywords: Powder metallurgy; Composites; Pressure infiltration

1. Introduction

An increased interest is observed in last years in metal matrix composite, mostly light metal based, which have found their applications in many industry branches, among others in the aircraft industry, automotive-, and armaments ones, as well as in electrical engineering and electronics, etc. [1,2].

Aluminium based composite materials are leading ones in this area, they are fabricated using many methods, including powder metallurgy processes, and then formed, e.g., by hot extrusion. Powder metallurgy makes materials properties relatively easy to control by mixing materials with different properties in various proportion.

The metal matrix composite can be reinforced with particles, dispersoids or fibres. However, the biggest interest in composite materials is observed for those reinforced with hard ceramic particles due to the possibility of controlling their tribological-, heat- or mechanical properties by selection of the volume fractions, size, and distribution of the reinforcing particles in the matrix [3]. They are used more often, compared with the composite materials of other metals, due to the broad range of their properties, and also due to the possibility of replacing the costly and heavy elements made from the traditionally used materials [4,5].

Two main development directions of manufacturing metal matrix composite materials technology are observed: powder metallurgy and casting methods, with specific modification of the pressure infiltration of the porous, ceramic preforms with liquid metals alloys.

Using the extrusion process it is possible to fabricate products with different geometries like solid and hollow profiles, with a fixed or varying transverse section. There are also some shortcomings of the extrusion process, and thus shortcomings of the extruded products, which are characteristic of the significant variations of their properties along their axis, and especially in their transverse section which are connected with the various degree of deformation during the extrusion process.

Deformation behaviour at extrusion temperature is dependent on many metallurgical and technological factors, e.g: temperature, flow rate, and extrusion ratio [6]. The advantage of extrusion process is possibility of making extruded products with high dimensional accuracy.

Pressure infiltration 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 [7-14]. The usage of infiltration process as the high-profitable technology is a base of getting the wide range of composite materials and allows to obtain the following technological-organizational profits [15]: 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.

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 open porosity allowing the liquid metal to flow as easily as possible. The occurrence of the closed pores or blind canals causes the formation of micro voids. Several fundamental development ways of porous ceramic material manufacturing are observed but sintering of ceramic powders with the addition of pores forming agent is the most flexible method and allows obtaining the diverse structure materials and ceramic phase content. The level of porosity and its character can be adjusted with different pore forming agents (PFA) addition, that are degradated in high temperature in the areas where the pores are originated [16-21].

Fabrication of the composite materials is focused on obtaining materials with improved properties compared to the matrix material.

The goal of this work is the presence and comparison of two aluminium matrix composite materials reinforced by Al_2O_3 manufacturing technologies. The first is focused on the powder metallurgy methods and by hot extrusion whereas the second of pressure infiltration process of ceramic porous preforms with the liquid EN AC - AlSi12 alloy.

2. Experimental procedure

The investigations were made of the composite materials obtained with two different methods:

The powder metallurgy methods and by hot extrusion of the EN AW-AlCu4Mg1(A) aluminium alloy (table 1).

The second material was produced by pressure infiltration method of porous ceramic preforms with liquid casting aluminium alloy. The EN AC - AlSi12 alloy features the matrix material, (chemical composition is presented in Table 2) and as the reinforcement the porous ceramic performs consisted of sintered Al_2O_3 particles were used.

Table 1.
Chemical composition of EN AW-AlCu4Mg1(A) aluminium alloy, % vol. [22]

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	the others	Al
0.24	0.1	1.2-1.5	0.1-0.3	1.9-2.9	0.04	0.10	0.09	0.20	the rest

Table 2.
Chemical composition of EN AC-AlSi12 aluminium alloy

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

Powders of the starting materials were wet mixed (methanol slurry) in the laboratory vibratory ball mill to obtain the uniform distribution of the reinforcement particles in the matrix. The mixed powders were then dried in the air.

The components were initially compacted at cold state in a die with the diameter of ∅ 26 mm in the laboratory vertical unidirectional press – with a capacity of 350 kN. The obtained PM compacts were heated up to a temperature of 480÷500˚C and finally extruded – with the extrusion pressure of 500 kN. Bars with the diameter of 8 mm were obtained as the end product.

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 ceramic preforms included: preparation of powder and carbon fibres mixture, pressing of prepared powder mixture, compact sintering.

The addition of the carbon fibres was 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 obtained ceramic performs is 80.80%.

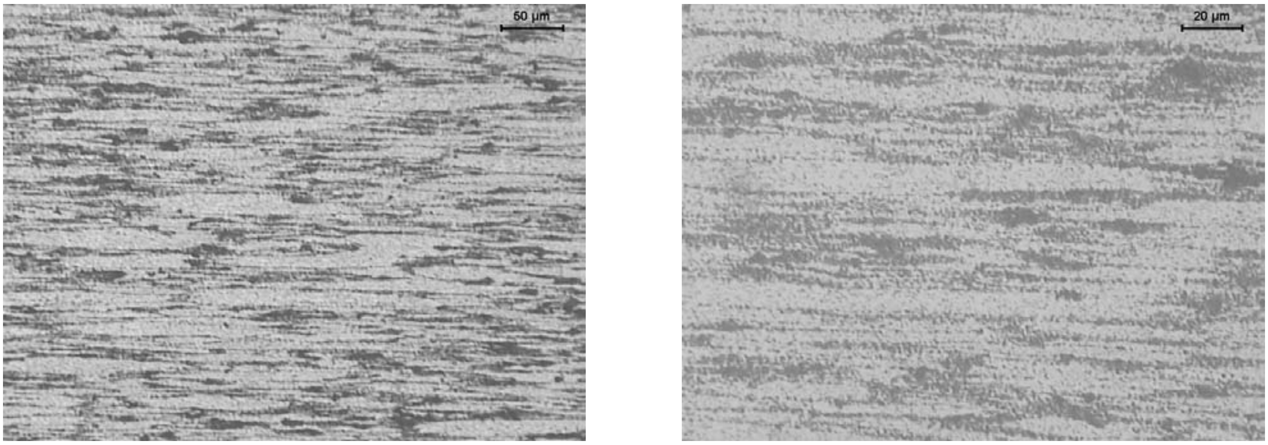

Fig. 1. Microstructure of longitudinal section of EN AW-AlCu4Mg1(A) aluminium alloy matrix reinforced Al_2O_3 particles ceramics

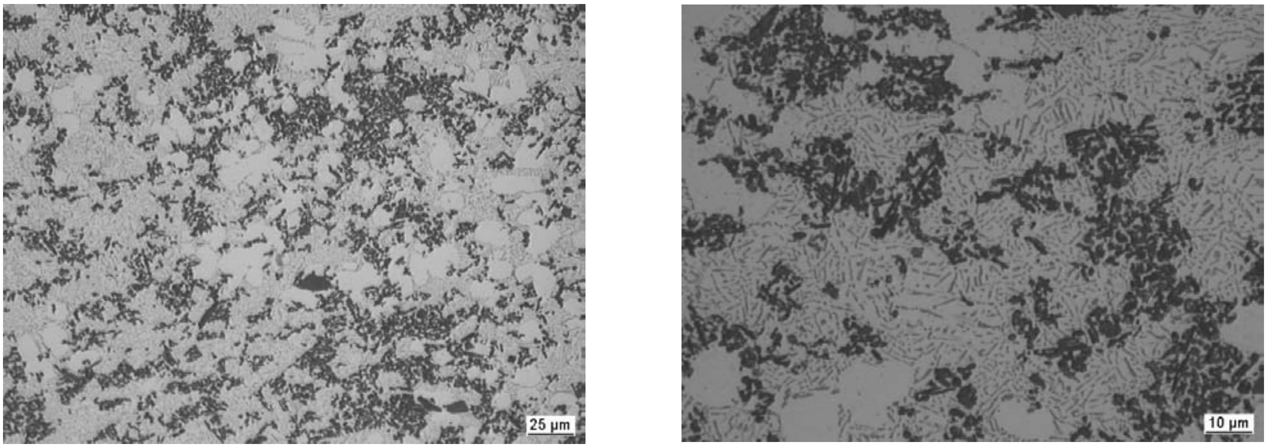

Fig. 2. Structure of the composite material fabricated by infiltration of ceramic preform obtained by sintering of Al_2O_3 particles

Prepared ceramic preforms were heated in furnace up 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 load was 120 s. After solidification obtained materials ware removed from the form and cool down under pressured air stream.

The metallographic examinations of the obtained composite materials were carried out on the LEICA MEF4A light microscope to investigate the structure to determine the distribution of the reinforcing particles in the matrix on the cross sections longitudinal in respect to the extrusion and infiltration direction of the composite materials.

3. Results and discussion

The metallographic examinations of both investigated composite materials make it possible to observe the homogeneous distribution of the reinforcing material in the matrix. In the case of material manufactured by extrusion method banding of the reinforcing particles parallel to the extrusion direction was noted on the longitudinal microsections (Fig. 1).

Moreover there were observed agglomerations of reinforcement particles, their segregation, and nonnumerous pores propobly coming from not exact intermixing of aluminium alloy powder with reinforcement particles and small deformation level during extrusion.

In the case of composite materials fabricated by pressure infiltration method of ceramic performs with liquid aluminium alloy has also been proved that the infiltration process is taking place at full level what confirms lack of pores in the material (Fig. 2).

It was found out that the presented technologies of fabrication the composite material with aluminium alloy matrix reinforced with the Al_2O_3 particles, consisting in the extrusion and infiltration makes a possibility of obtaining new materials, ensures the required structure, and therefore may find practical applications.

4. Conclusions

Both presented methods of aluminium matrix composite materials reinforced by ceramic particles manufacturing ensures required structure and can be applied in practice.

Undoubtedly advantageous of powder metallurgy method is possibility of manufacturing small elements near net shape while pressure infiltration method allow to manufacture locally reinforced elements from composite materials with good surface quality, but is more energy consuming than powder metallurgy and this is the main restriction of its application.

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