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A.J. DOLATA*

CENTRIFUGAL CASTINGS LOCALLY REINFORCED WITH POROUS Al_2O_3 PREFORM

ODLEWY ODŚRODKOWE LOKALNIE WZMOCNIONE POROWATĄ PREFORMĄ Al_2O_3

The main objective of presented researches were tests of infiltration of the porous ceramic preforms at the pressure in centrifugal casting process. Make an assumption that the porous preform will be create the local reinforcement layer in specific area of the casting. For investigations the alumina porous ceramic preforms were applied (Al_2O_3). The pressure to infiltrate molten aluminum alloy into ceramic preforms was generated by centrifugal force. The structure of composites was examined by light and electron microscope. The investigations of composites microstructure exhibited high degree of infiltration of spherical macropores in Al_2O_3 ceramic preforms by the molten aluminium alloy. On the basis of structural studies has been shown that centrifugal force is effective as a driving force for the infiltration of porous preforms.

Keywords: aluminium casts, porous performs, centrifugal infiltration, structure

Głównym celem przedstawionych badań była próba infiltracji porowatych preform ceramicznych wspomagana ciśnieniem generowanym w procesie odlewania odśrodkowego. Założono, że porowata preforma będzie tworzyć lokalne wzmocnienie w określonym obszarze odlewu. W badaniach wykorzystano preformy ceramiczne (Al_2O_3). Ciśnienie niezbędne do infiltracji ceramicznej preformy ciekłym stopem aluminium było generowane za pomocą siły odśrodkowej. Strukturę kompozytu badano z wykorzystaniem mikroskopii świetlnej i elektronowej. Badania mikrostruktury kompozytów wykazywały wysoki stopień infiltracji sferycznych makroporów preformy Al_2O_3 przez stop aluminium. Na podstawie badań strukturalnych wykazano, że siła odśrodkowa działa jako siła napędowa i wspomaga proces infiltracji porowatych preform.

1. Introduction

The range of applications of machine parts made from casting aluminium alloys develops more and more. They are used for many industrial applications, particularly in the automotive industry [1]. The generally known advantages of aluminum alloys, such as light weight, good mechanical behavior and good corrosion resistance are the driving force for the development of their new applications and new processing solutions [2]. At present the applications of aluminum alloys in particular includes: pistons, cylinder blocks and heads, brake cylinders, sleeves and suspension arms. However, especially in the automotive engineering and aerospace the aluminium components must work under ever more difficult conditions [3]. One of the solutions to improve their properties are connection lightweight aluminium alloys with advanced ceramic materials [4-15]. The motivation to use of Aluminium Matrix Composites (AMCs) in the automotive and aerospace industry is to maintain of low weight next to increasing others properties particularly: dimensional stability in high temperature, high specific strength, stiffness, hardness but also lower wear and corrosion resistant [5,15]. Therefore in over the past years, AMCs are introduced for the production as a promising class of materials. Especially Al/Al_2O_3, Al/SiC and hybrid composites for their unique thermal and tribological properties have a great perspective [8,9,12-16,]. But still, these materials are largely unsuccessful commercially. The intensive wear of the machine parts cooperating with the composite elements and machinability of such materials it still the problems which require resolved [17].

Therefore in recent years there have been many papers concerning the possibility of creating gradient in composite materials or local reinforcement in the specific area of finished product [18-22]. These ways gives the possibility connect principal advantages of aluminium alloys i.e. good plasticity and machinability with desirable properties of advanced ceramic materials, such as: high hardness, thermal resistance, stability of dimension and corrosion resistance. Among different methods used for AMCs production a significant are infiltration processes, which can be classified into some categories, i.e. the infiltration assisted by external pressure, the vacuum or gas infiltration and the pressureless infiltration in protective atmosphere, [6,7,10,11,17-24].

The main objective of presented investigations is infiltration of the porous ceramic preforms by the molten aluminium alloy under pressure created by the centrifugal force. Make an assumption that the porous preforms will be create the reinforcement layer in specific area of the casting to aim its

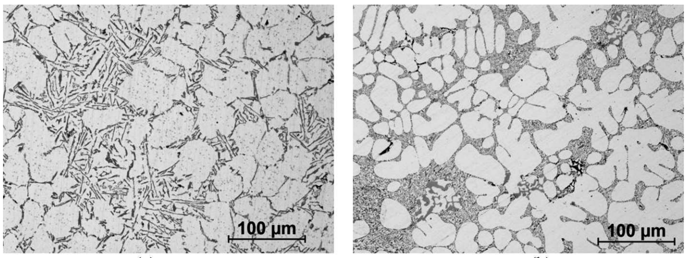
* SILESIAN UNIVERSITY OF TECHNOLOGY, FACULTY OF MATERIALS SCIENCE AND METALLURGY, 8 KRASIŃSKIEGO STR., 40-019 KATOWICE, POLAND

strengthen in the most loaded places. The researches presented in this work are a fragment of investigations conducted by author regarding the application of liquid processes, including centrifugal casting for shaping of functional structure in metal matrix composites [8-12,14,15,22,23].

2. Materials and Methods

The structure of components, matrix alloy and porous preform as well as centrifugal casts were examined by light (LM) and scanning electron microscopy (SEM).

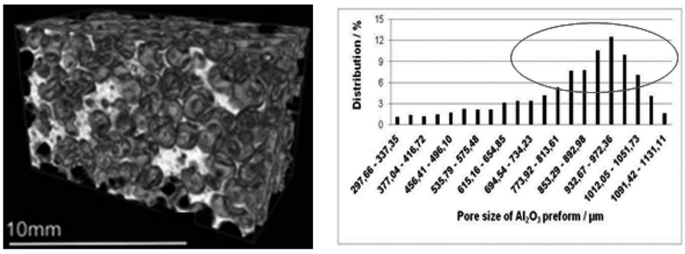
On the matrix of composite, a eutectic silicon aluminium alloy was applied, EN-AC- AlSi12CuMg. The chemical composition of the commercial alloy was modified additionally by 1 wt. % Mg and 0.03 wt. % Sr additions. The magnesium to improve the wettability between aluminium matrix and ceramic reinforcement was added. In turn the 0.03% strontium addition was used to change the size and morphology of the Al-Si eutectic grains. The structure of modified and unmodified alloy were presented in Figure 1.



(a) (b)

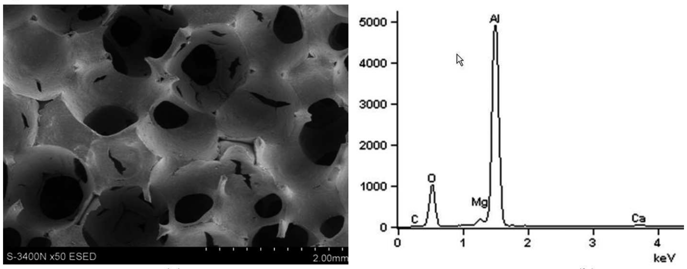
Fig. 1. Structure of EN-AC-AlSi12CuMgNi aluminium alloy, LM: a) unmodified; b) modified

For centrifugal infiltration process the porous aluminum oxide preforms (Al_2O_3) were applied. The Al_2O_3 preforms were made at the Institute of Ceramics and Building Materials in Warsaw [10,11]. The image of the porous Al_2O_3 ceramics obtained using X-ray tomography and distribution of pores size were presented on Figure 2. The volume fraction of the ceramics phase was approximately 25 vol.%, the remaining area (74 vol.%) was assigned for filling up with liquid aluminium alloy. The Al_2O_3 preform was characterized by the biggest pores size. The typical cylindrical shape of Al_2O_3 preform and element analysis on ceramic surface were presented in Figure 3.



(a) (b)

Fig. 2. Porous Al_2O_3 ceramic perform: a) X-ray tomography image, b) distributions of pores size



(a) (b)

Fig. 3. SEM image of Al_2O_3 porous preform in foam shape, (a) and chemical analysis on porous ceramic surface, (b)

For manufacture of investigated composite materials the equipment designed and constructed at the Silesian University of Technology were used, [22]. The centrifugal infiltration process was carried out by the casting of molten aluminium alloy into the rotating mold. The centrifugal mold were heated to 250°C. The pouring temperature was a range from 720-740°C. In casting process were used one rotational speed the 4000 rpm. The view of chamber and shape of rotating mould were presented in Figure 4. Inside centrifugal mould before pouring, the Al_2O_3 porous preform have been placed.

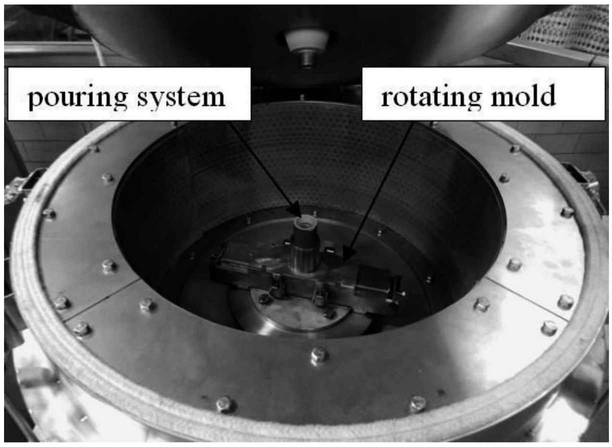


Fig. 4. The view of chamber and shape of centrifugal mould in equipment used for infiltration process

3. Results and discussion

The molten aluminum alloy casted into a graphite mould, and then begins infiltration the porous preform at the pressures generated by the centrifugal force. Representative of the macroscopic images of centrifugal casts with local strengthening by ceramic preform, obtained at 4000 rpm, have been shown in Figure 5.

Microstructural characterization of the centrifugal cast was performed in two areas. Area without reinforcement and the area of locally strengthened by ceramic preform were observed (area 1 and area 2 are visible on the Fig. 5b). For the structure analyses the methods of light and scanning microscopy were used. Moreover, local analyses of chemical compositions using an EDX module were performed. The obtained casts in unreinforced areas were characterized by a structure about prescribed chemical and phase composition, which is in correlation with the phase composition of the used aluminium alloy. The selected, representative microstructure of AlSi12CuMg matrix alloy in area 1 were presented in Figure 6.

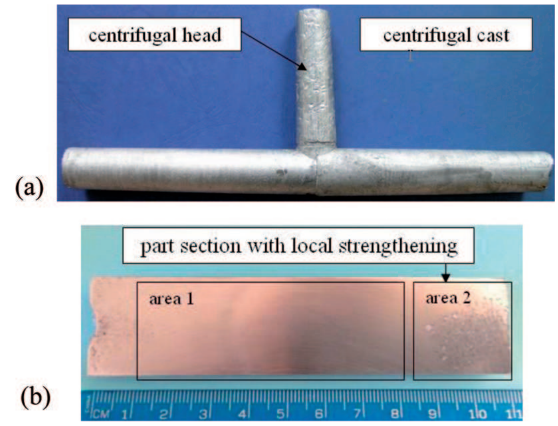


Fig. 5. Centrifugal cast: a) view of ready composite cast with head, b) view of part section with local strengthening (area 2) and without reinforcement (area 1)

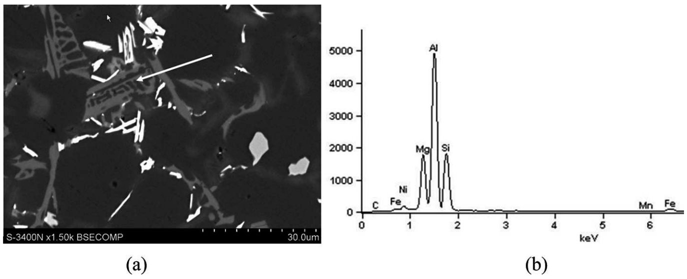


Fig. 6. SEM micrograph showing the alloys' microstructure in area 1, (a) and selected results of chemical analysis in the micro-volume indicated by arrow, (b)

On the basis of microstructural observations of composites in area of local reinforcement, performed at small magnification, was found continuous connection between the Al_2O_3 porous preform and the aluminium matrix alloy (Fig. 7). Similarly, the microstructural observations of the centrifugal casts by means of scanning electron microscope (SEM) confirmed good filling pores in ceramic preform by the aluminium alloy (Fig. 8). At the interface between ceramics and matrix alloy was observed a slight increase in the concentration of magnesium, (Fig. 9).

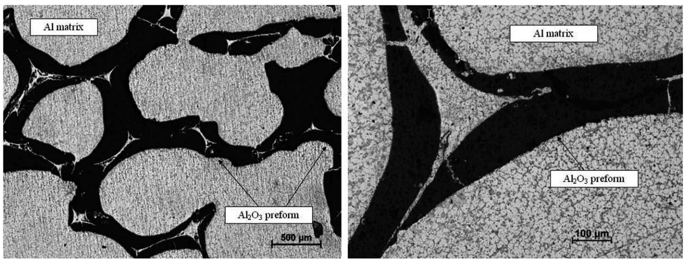


Fig. 7. Microstructure of centrifugal cast in area 2 with visible local reinforcement, LM

The contact angle of alumina oxide with molten aluminum alloy is greater than 90° [25]. As shown the EN-AC-AlSi12CuMg alloy modified by Mg addition filling the Al_2O_3 preform in spite of poor wetting properties. Magnesium in aluminium alloy reacted with oxygen which can leads to the formation of MgO or $MgAl_2O_4$ spinel phase, in accordance with reactions:

$$Al_2O_3 + 3Mg \rightarrow 3MgO + 2Al \tag{1}$$

$$Al_2O_3 + MgO \rightarrow MgAl_2O_4 \tag{2}$$

The spinel layer is formed during the oxide wetting. The possible reactions dependent on the time, temperature and concentration of magnesium in the alloy, [26]. The composite structure analysis has confirmed, that the presence of magnesium in aluminium matrix alloy is necessary because improves the adherence on the boundary between components. The combinations of magnesium and aluminium have synergistic effect on wetting. Moreover, in the proposed technological solution the additional pressure induced by the centrifugal force is helpful and influences on proper degree of infiltration of molten aluminium alloy in ceramic pores.

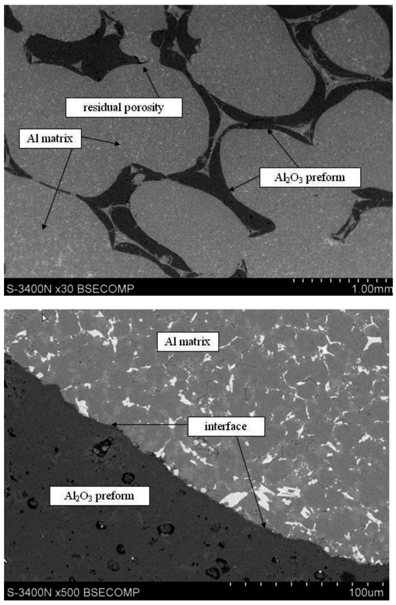


Fig. 8. SEM images of centrifugal cast in area 2 with visible local reinforcement

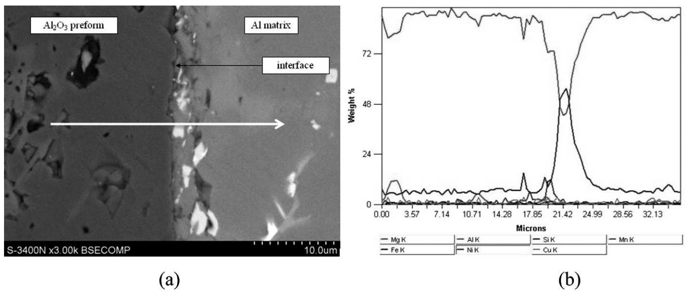


Fig. 9. Representative SEM image in boundary area between Al matrix alloy and Al_2O_3 preform, a) and EDS line mapping in the area marked by the arrow

4. Summary

On the basis on preliminary results of presented investigations have been proved that centrifugal force is effective as a motive force for the infiltration of alumina porous preforms by the molten aluminium alloy. The investigations of composites microstructure exhibited a very good infiltration of Al_2O_3 porous preforms by the molten aluminium alloy. According to the initial assumptions, the porous preforms forms the reinforcement layer in specific area of the cast and strengthens the material in the most loaded places. As demonstrated results of technology tests, the centrifugal casting could be effective ways to production of special composite castings. In further researches the process optimization, the selection of components (matrix and preforms), detailed analysis of the microstructure, especially in the interlayer between matrix and the ceramic reinforcement and moreover evaluation of properties have been planned.

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