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Structure and properties of aluminium-silicon matrix composites manufactured by pressure infiltration method

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ABSTRACT

Purpose: The goal of the paper is to develop technologies for manufacturing composite materials with casting aluminum alloy matrix reinforced by silicon AN AC-AlSi12 and to investigate the effect of the amount of the pore forming agent in the form of graphite MG 192 on the structure and properties of porous ceramic skeleton infiltrated with liquid aluminum alloy.

Design/methodology/approach: The composite was manufactured by the use of porous material pressure infiltration method. Hardness test was carried out with Rockwell method in A scale. The wear resistance was measured by the use of TSM Instruments Tribometer. The tribomiter allows to realize dry friction wear mechanism conditions. Additionally the examinations on stereomicroscope of wear tracks were made.

Findings: Composite materials reinforced by porous skeleton manufactured on the base Al_2O_3 particles show superior in mechanical properties and wear resistance than the aluminum alloy EN AC-AlSi12 constituting the matrix. The developed composite materials also have better wear resistance compared to the matrix.

Practical implications: Tested composite materials can be applied in many industry branches, among others, in the automotive, aerospace industry and in manufacturing of professional sports equipment.

Originality/value: The investigation results shows that the worked out technology of composite materials manufacturing can find the practical application in the production of near net shape and locally reinforced elements.

Keywords: Composites; Ceramic preforms; Infiltration; Wear coefficient

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MATERIALS

1. Introduction

An especially preferred feature of the composite materials is the ability to design the structure in a direction to obtain the assumed properties [1,2]. The ability to achieve the corresponding properties allows for their perfect combining, in terms of their operating conditions, and thus resistance to wear, corrosion, fatigue, improved conduction of heat and electricity, magnetic properties and others [3].

The properties of composite materials can be designed in a much greater degree than in the case of other materials [4]. Their achievement is possible among others by selecting a suitable matrix and the type of reinforcement.

To obtain desired properties is also important a method of producing composite materials [5-7]. Among the many techniques for the manufacturing of composite materials can be distinguished pressure infiltration method, which is a connection of powder metallurgy and foundry technologies.

Pressure infiltration is the most cost-effective and comprehensive process for the preparation of composite materials based on aluminium alloys. To the advantages of the pressure infiltration process can be included [8,9]:

- the relatively low cost of the matrix material,
- small risk of mechanical destruction of reinforcement material,
- high rate of manufacturing,
- the possibility of obtaining elements with net shape and surface,
- the possibility of local casting strengthening,
- possibility of using any material matrix and reinforcing phase.

The main disadvantage of this process are higher requirements for instrumentation and the external pressure generating apparatus [10].

Infiltration pressure can be divided depending on the agent causing the metal penetration in porous ceramic skeleton [3-11]:

- vacuum infiltration – in which the preform (in comparison to atmospheric pressure), is under reduced gas pressure. The factor causing infiltration process is a positive pressure of molten metal,
- retorting infiltration – in which the hydrostatic pressure exerted on the metal-to-preform arrangement allows the infiltration of porous material,
- low pressure infiltration – in which the pressure is involved, at a value from several to several hundred Pascals, on situated above the surface of the molten metal gas, as a result of which comes to its penetration into the porous preform,
- high pressure infiltration – in which the metal, is under pressure from tens to a few hundred MPa, flows into the pores of the preform, where then solidifies
- gas-vacuum infiltration, which is a combination of vacuum infiltration (ceramic skeleton before introduction into the liquid metal under reduced pressure) and pressure (the pressure on the gas above the liquid metal mirror).

The most preferred type is gas-vacuum infiltration, as during the process a porous ceramic skeleton and the alloy used for the penetration are in a protective atmosphere (vacuum during the melting of the alloy and an inert gas after the introduction of the liquid metal skeleton). Furthermore, vacuum assisted infiltration reduces pressure on the liquid metal, since the real pressure must be applied to previously produced vacuum rather than to atmospheric pressure, as in the conventional pressure infiltration.

It is very important due to the fact that the melt pressure must not exceed the limit value that sets the strength of the ceramic skeleton. A very important advantage coming from application the gas-vacuum infiltration method is low porosity of the final composite material resulting from the fact that during the penetration of the liquid alloy migration does not occur outside the skeleton of the gas contained within the channels and its compression in the "dead" times which is the direct cause microporous in the composite material [12-15].

The goal of the paper is to develop technologies for manufacturing composite materials with casting aluminium alloy matrix reinforced by silicon AN AC-AlSi12 and to investigate the effect of the amount of the pore forming agent in the form of graphite MG 192 on the structure and properties of porous ceramic skeleton infiltrated with liquid aluminium alloy.

2. Experimental procedure

Material for the study was manufactured by pressure infiltration of the porous ceramic skeleton with liquid aluminium alloy. The matrix was a nearby eutectic casting aluminium alloy with silicon EN AC-AlSi12, the chemical composition shown in Table 1.

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

As reinforcement was used the porous ceramic skeleton formed by sintering a powder containing Al_2O_3 pores forming agent in the form of flake graphite MG 192 of the mass fraction of 30%. Typical parameters used flake graphite is shown in Table 2.

Table 2.
Properties of flake graphite MG 192

Carbon content min.	Grain size	% fraction / expansion	Humidity max	Bulk density
92%	< 0.15 mm	90%	3%	~0.5 g/cm^2

The process for preparing porous ceramic skeletons consist of several steps: preparing a powder, pressing and sintering.

To produce ceramic skeletons Al_2O_3 powder was used, which to break up agglomerations of particles was subjected to wet milling with distilled water in a planetary ball mill Pulverisette 6 Fritch Company.

The ratio by weight of the material to the grinding media in the form of zirconium oxide beads was 1/10. Then, to the slurry of Al_2O_3 was introduced 30% graphite, which blowing agent, 3% addition of 64 Dolapix CE manual Zschimmer & Schwarz GmbH, eliminating electrostatic actions between the graphite flakes, 1% polyvinyl alcohol dissolving in water, added for easier pressing.

Then, the slurry powder mixtures were dried in a freeze dryer Vacuum SRK Systemtechnik GmbH enables the freezing and drying the ceramic slurry in water by sublimation of ice at reduced pressure. The dried powder was sieved through a sieve having a mesh size of 0.25 mm, and wetted with distilled water (1%) to activate the polyvinyl alcohol.

Prepared mixture of ceramic powders and graphite was subjected to uniaxial pressing on plate hydraulic press Fontijne LabEcon's 600 Presses in a steel die having an inner diameter of 30 mm. Compaction pressure was 100 MPa, and the time of its impact 20 s.

Sintering the compacts made in the furnace chamber FCF 4 / 160M / PG Czylok Company in air atmosphere included the following steps:

- slow heating up to the temperature 800°C at a rate of 30°C/h,
- holding at this temperature for 5 h for total thermal degradation of the graphite,
- heating to a temperature of 1500°C at a rate of 300°C/h,
- sintering for 2 h,
- cooling of the furnace.

Temperature of the sintering process is shown in Fig. 1.

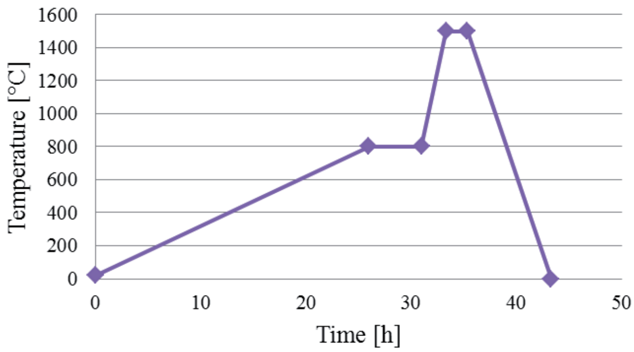

Fig. 1. Sintering process

After removing specimens from the oven it was observed a change of their colour from grey to white. This indicates total degradation of graphite by sintering. Figure 2 shows the mouldings (Fig. 2a) and ready-porous ceramic skeletons (Fig. 2b).

a)

b)

Fig. 2. a) Mouldings of Al_2O_3 mixture with graphite, b) a porous ceramic skeletons

The last step in the manufacturing process of the composite material was vacuum-pressure infiltration by hot aluminium-silicon alloy EN AC-AlSi12. For this purpose the heating device for pressure impregnation of porous mouldings with two heating zones allowing simultaneous heating and melting the metal specimens was used. The temperature of the ceramic skeleton and aluminium alloy was 800°C, pressure infiltration 30 bar (compressed nitrogen from a cylinder) during 1 minute. Device for pressure-vacuum infiltration is shown in Fig. 3.

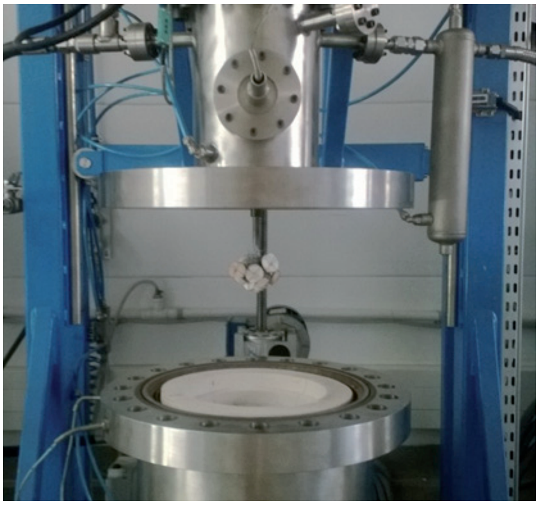

Fig. 3. Device for vacuum-pressure infiltration

Metallographic examinations of the composite materials with aluminium alloy EN AC-AlSi12 matrix reinforced by Al_2O_3 porous preforms were made on the light microscope LEICA MEF4A. Specimens were not etched to observe the structure (ceramic phase distribution in the metal matrix) and the infiltration degree. Fractographic examinations of obtained ceramic porous preforms were made on the Zeiss Supra 35 scanning electron microscope.

Hardness test was carried out on hardness measuring instruments Zwick/ZHR. It was done with Rockwell method in A scale. The test was taken out according to the standard PN-EN ISO 14577-1:2003.

Research of tribological properties of composite materials and the matrix material was made using a CSM Instruments Trybometr by pin-on-disc method. As counter-sample was used ceramic balls diameter of 6 mm. The test was carried out at a constant load of 10 N and a frequency of 2 Hz. The linear speed of the samples was 3 cm/sec, and wiping covered area with a radius of 7 mm. After finishing the test, traces were examined using profilometer Taylor-Hubson Sutronic 25 cooperating with trybometer. Application of software TRIBOX allows to determine cross-sectional area and the calculated volume of wear caused cavities.

3. Results

Structures observed in a scanning electron microscope allowed the analysis of surface topography on the fractures of porous skeletons. Studies shown homogenous distribution of pores in the ceramic skeletons. There was no occurrence of clusters of pores, which testifies to the proper addition of the centre Dolapix CE 64 added in order to prevent the formation of agglomerates and the elimination of electrostatic interactions between the graphite flakes. Observations have also shown small pores present around the individual particles of Al_2O_3 which existence is due to deliberate lack of compaction of the material by applying a greater compression pressure or a higher sintering temperature. The structure of the ceramic breakthroughs skeletons are shown in Figure 4.

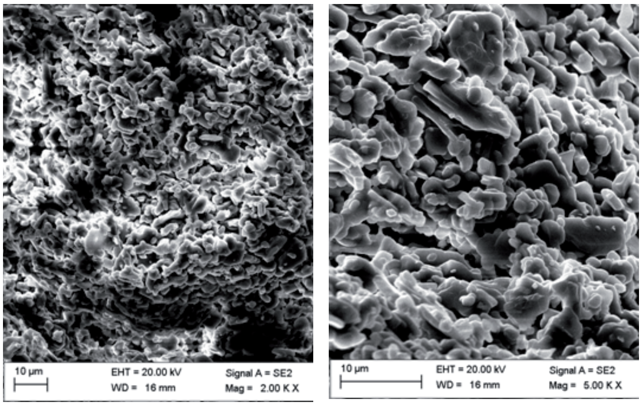

Fig. 4. Structure of porous ceramic of the skeleton

Observations under light microscopy of metal matrix composite materials manufactured by pressure infiltration of the porous ceramic skeleton formed by sintering process revealed a uniform distribution of reinforcing phase in the matrix, in addition, there was no significant difference in the structure of composite materials according to the plane of specimens (Fig. 5).

As a result of hardness measurements of investigated composite material was found twice its height (61 HRA) in comparison to the matrix, which is an alloy EN AC-AlSi12 (30 HRA).

On the base of abrasion resistance test of composite materials manufactured and matrix material it was estimated that the average coefficient of friction, which was 0.51 and 0.44 respectively.

As far as the wear of test materials was assumed a trace of wear volume calculated on the basis of analysis of the profiles (Fig. 6).

a) b)

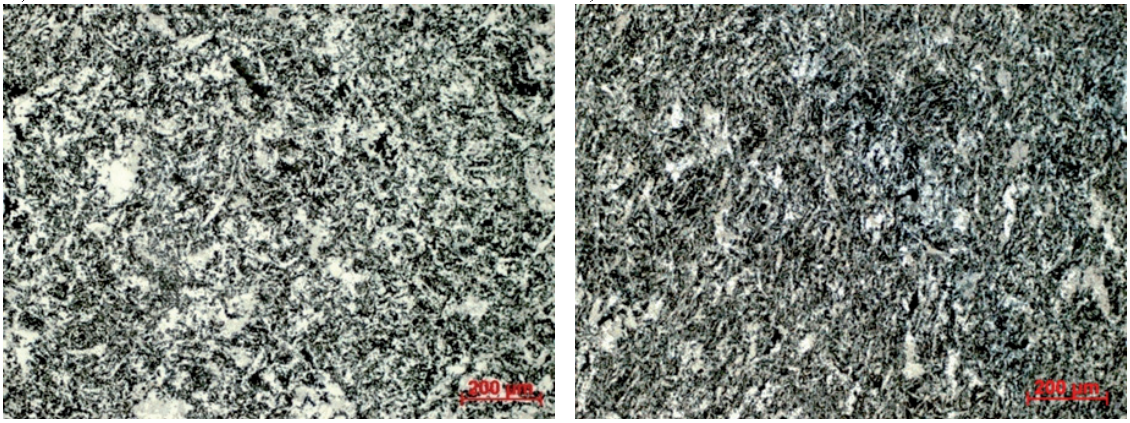

Fig. 5. Structure of investigated composite material: a) longitudinal metallographic section, b) the transverse metallographic section

a)

b)

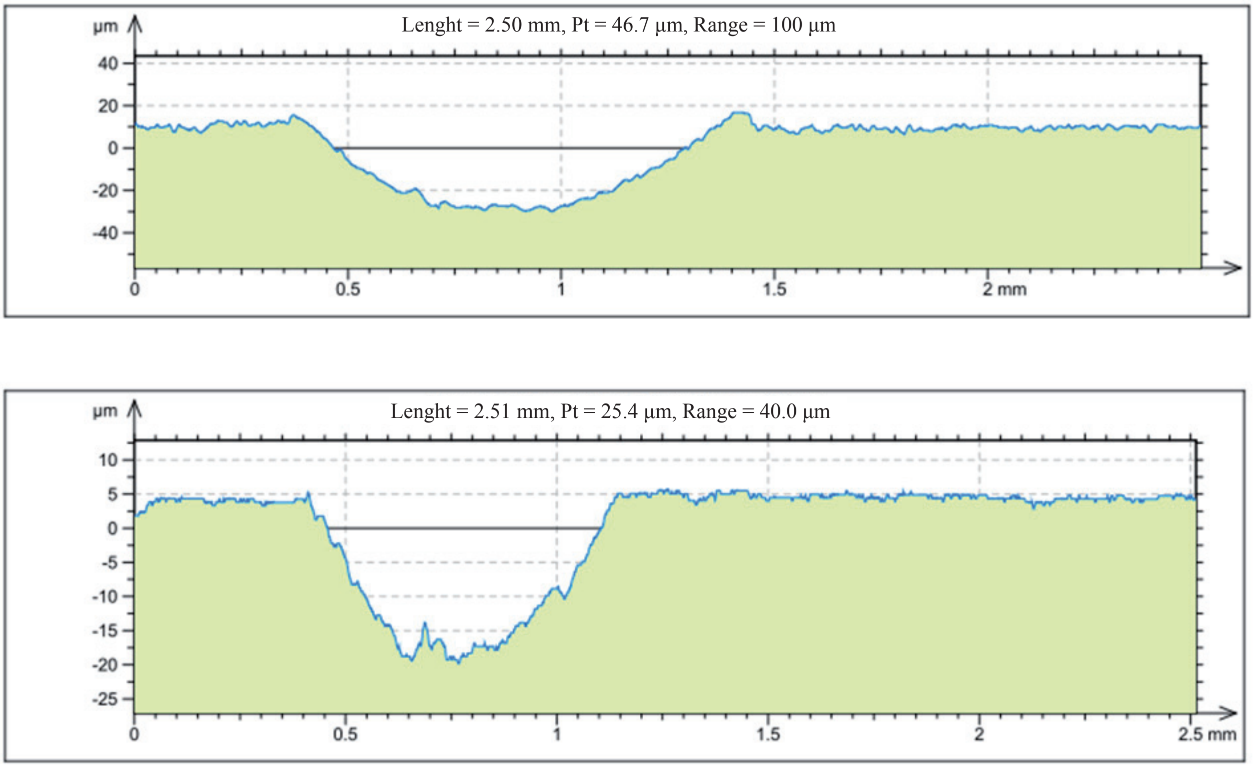

Fig. 6. Wear profile of the: a) matrix material, b) investigated composite material

The wear volume of the matrix material is 0.17 mm^3 while the investigated composite material is almost three times less and is 0.42 mm^3.

4. Summary

Flake graphite is a very good pore forming agent because it undergo the total thermal degradation. In contrast to other pore forming agent such as cellulose, the use of graphite does not produce additional products in the material, and does not contribute to produce a bloom on the walls of the furnace during sintering. Degradation of the graphite product is mainly CO_2, whereby a high purity process.

Developed porous skeletons are characterized by a uniform distribution of the ceramic phase. Pressure infiltration of the porous moulded allows obtaining composite materials characterized by a uniform distribution of reinforcing phase in the matrix. The materials have isotropic structure

Composite materials reinforced with porous skeletons manufactured on the base of Al_2O_3 particles have a higher hardness and wear resistance than the aluminium alloy EN AC-AlSi12 constituting the matrix.

The technology of producing composite materials which consists of a pressure infiltration of the porous ceramic skeletons allows the manufacture of composite material with a desired structure and properties. The materials produced by this method can be widely used in practice.

References

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

[2] K. Przybyłowicz, J. Przybyłowicz, Non-metallic materials and composites, Edition III, Publisher Kielce University of Technology, Kielce, 2002.

[3] J. Sobczak, A. Wojciechowski, D. Rudnik, The departed pressure in the production of composite materials: analytical study of literature, Publishing House of the Institute of the Motor Transport, 2008.

[4] J. Sobczak, S. Wojciechowski, The current trends in the practical application of metal matrix composites, Composites 2/3 (2002) 24-37 (in Polish).

[5] A. Dolata-Grosz, M. Dyzia, J. Śleziona, Structure of Al-CF composites produced by methods of infiltration, Archives of Foundry Engineering 11/2 (2011) 23-28.

[6] M. Kaczorowski, A. Krzyńska, Structural materials of metal, ceramic and composite, Warsaw University of Technology Publishing House, Warsaw, 2008.

[7] K. Oczoś, Fibre reinforced composites – properties, application, machining, The Machinist 81/7 (2008) 579-592 (in Polish).

[8] L.A. Dobrzański, M. Kremzer, A.J. Nowak, A. Nagel, Aluminum matrix composites fabricated by infiltration method, Archives of Materials Science and Engineering 36/1 (2009) 5-11.

[9] Z. Zarański, I. Łosik, Z. Bojar, Investigations of continuous carbon fibre surface after modification process, Composites 2/5 (2002) 318-322 (in Polish).

[10] W. Piekoszewski, W. Tuszyński, An effect of the type and concentration of lubricating additives of AW/EP properties and rolling fatigue life of a tribosystem, Tribology 5 (2003) 203-220 (in Polish).

[11] J. Sobczak, Metal composites, Publishing Institute of Foundry and Motor Transport Institute, Cracow-Warsaw, 2001.

[12] L.A. Dobrzański, M. Kremzer, M. Adamiak, The influence of reinforcement shape on wear behaviour of aluminium matrix composite materials, Journal of Achievements in Materials and Manufacturing Engineering 42/1-2 (2010) 26-32.

[13] L.A. Dobrzański, M. Kremzer, W. Sitek, The application of statistical models in wear resistance simulations of Al-$A1_2O_3$ composites, Archives of Materials Science and Engineering 43/1 (2010) 5-15.

[14] L.A. Dobrzański, M. Kremzer, M. Dziekońska, Possibility of wettability improvement of Al_2O_3 preforms infiltrated by liquid aluminium alloy by deposition Ni-P coating, Archives of Materials Science and Engineering 55/1 (2012) 14-21.

[15] L.A. Dobrzański, M. Kremzer, J. Konieczny, The influence of Ni-P layer deposited onto Al_2O_3 on structure and properties of Al-Al_2O_3 composite materials, Journal of Achievements in Materials and Manufacturing Engineering 46/2 (2011) 147-153.