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ABRASIVE WEAR OF AlSi12-Al_2O_3 COMPOSITE MATERIALS MANUFACTURED BY PRESSURE INFILTRATION

The aim of this study is to investigate tribological properties of EN AC-AlSi12 alloy composite materials matrix manufactured by pressure infiltration of Al_2O_3 porous preforms. In the paper, a technique of manufacturing composite materials was described in detail as well as wear resistance made on pin on disc was tested. Metallographic observations of wear traces of tested materials using stereoscopic and confocal microscopy were made. Studies allow concluding that obtained composite materials have much better wear resistance than the matrix alloy AlSi12. It was further proved that the developed technology of their preparation consisting of pressure infiltration of porous ceramic preforms can find a practical application.

1. Introduction

Over the last twenty-five years, limit particulates matter and nitrogen oxides emission decreased by 97 and 95%, as shown in Figure 1. Car manufacturers impose more and more restrictive emission limits to change the approach to the design of vehicles, especially the luxury ones. The solution of this problem are various kinds of systems installed in vehicles such as Exhaust Gas Recirculation (EGR), Diesel Particle Filter (DPF) or Bosch Denoxtronic performing the processes of exhaust gas purification, mainly oxides of nitrogen (NOx), hydrocarbons (HC), carbon monoxide (CO) and particulate matter (PM). Further tightening of limits will need to drastically reduce fuel consumption in the manufactured vehicles. The restrictions should not result in a reduction car performance and hence the attractiveness of manufactured cars, modern material solutions for reducing their weight are needed. The answer to these needs, among the others, are light metal composite materials, mainly aluminium and magnesium matrix. Composite materials have properties unattainable in conventional monolithic materials. They are characterised by an increased: strength, Young's modulus, desirable fatigue properties, wear resistance, sliding characteristics, high corrosion resistance, either at room temperature as well as elevated temperature [1-10].

Conventionally manufactured composite materials consist of two phases: a matrix constituting the adhesive and ensuring consistency of the material, and the reinforcement forming the desired properties. The mostly, matrix is the continuous phase, while the strengthening continuity is determined by its shape and size. When long fibres are oriented in one direction or arranged in the form of mats, the reinforcement has an ongoing ability to independently carry loads. The use of particles or short fibres (discontinuous reinforcement) results that matrix always takes part in the load carrying. In this case, the main factor determining the properties of the composite material is formed during the process of the structure connection between its components [9, 11-20].

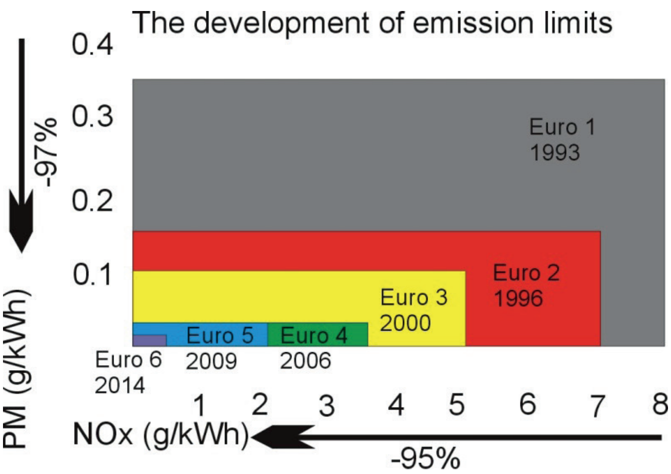

Fig.1. The development of emission limits [1, 2]

Pressure infiltration of porous ceramic preforms is the technology of producing composite materials (also reinforced with short fibres and particles) characterised by continuity both of the matrix and reinforcement. This method combines the techniques of casting (infiltration process) and powder metallurgy (preparation of porous sintered preforms). The infiltration process is the base for the preparation of a wide variety of composite materials and allows to obtain many benefits, wherein to the main, besides the continuous nature of reinforcement can be included the possibility of local product reinforcement. The base of composite materials produced by infiltration, are ceramic preforms being the porous bodies and primarily affecting the properties and structure of the final product. The structure should be an open, interconnected pores allowing the easiest possible flow of molten metal during the infiltration. Such structure provides a preform manufacturing

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technology consisting sintering of ceramic powders with the addition of pores forming agent, disintegrating at high temperatures and creating voids and gaseous degradation products themselves by passing out of the material forming channels, through which liquid metal will flow during the infiltration process [14,21-29].

The goal of the paper is to investigate the abrasion resistance of composite materials with casting aluminium alloy EN AC-AlSi12 matrix, produced by pressure infiltration of the porous preform, based on ceramic powder Al_2O_3.

2. Material and experimental procedure

The research material was produced by pressure filtration, which consisted of uniaxial pressing of liquid metal and porous ceramic preform. Near eutectic casting aluminium alloy EN AC - AlSi12 was used as a matrix, while as reinforcement the Al_2O_3 preforms produced by powder sintering method of Alcoa Cl 2500 powder with addition of carbon fibres Sigrafil C10 M250 UNS SGL Carbon Group being a pores forming agent. The use of the carbon fibres is cost effective both from the technological point of view, because the only product of their thermal degradation is CO_2, hence the sintering process does not require the use of pyrolysis, and also the final composite material, because the matrix finally takes shape of the degraded fibres that have a positive effect on the mechanical properties.

The manufacturing process of ceramic preforms included:

- preparation a mixture of Al_2O_3 powder with carbon fibres,
- pressing of prepared mixture,
- sintering.

Large agglomerates formed during the powder synthesis or storage are a common source of adverse closed pores in the sintered preform. Spaces formed between the crystallites inside these agglomerates are responsible for the formation of closed pores. Al_2O_3 powder was subjected to milling on wet in a planetary ball mill Fritch Pulverisette 6 in the ZrO_2 vessel with purpose to break agglomerates, the mass of powder ratio to grinding media was 1:10 and the milling time 10 min.

Polyvinyl alcohol Moviol 18-8 dissolving in water (binding agent) and the 30, 40 or 50% carbon fibres into the suspension were added. The mixture of powders prepared in such way was dried by freezing and water sublimation under reduced pressure. Dry powder sieved through a sieve No 250 was placed onto the flat surface, and the distilled water was sprayed to activate the polyvinyl alcohol. After 24 h powder was subjected to uniaxial pressing on a laboratory Fontijne TP 400 hydraulic press, in a steel mould 45x65 mm, under the pressure of 100 MPa for 15 s. Compacts were sintered in "Gero" pipe furnace in the air atmosphere (20 l/min). The temperature during the sintering process ensured the carbon fibres degradation (heating by 10 h in temperature 800 ºC) and Al_2O_3 powder sintering in temperature 1500 ºC by 2 h. The porosity of the ceramic preforms was established on the base of geometric measurement, referred to the theoretical volume of bulk material calculated by dividing the mass of the preform and the real density of Al_2O_3. The porosity depends on the carbon fibres content and is equal to 67% at 30% of carbon fibres addition, 76% at 40% and 80% at 50%, respectively.

All ceramic preforms were heated in the furnace up to temperature 800 ºC. Form covered by graphite was warmed up to 450 ºC (maximum temperature of the press plates) and fulfilled with preform and liquid alloy EN AC – AlSi12 at the temperature of 800 ºC. The chemical composition of the alloy is presented in Table 1. Then the sample was closed by the stamp and placed in the plate hydraulic press Fontijne TP 400. The maximum infiltration pressure was 100 MPa for 120 s. After solidification, obtained materials were removed from the form and cooled down under pressured air flow.

TABLE 1

Chemical composition of EN AC-AlSi12 aluminium alloy

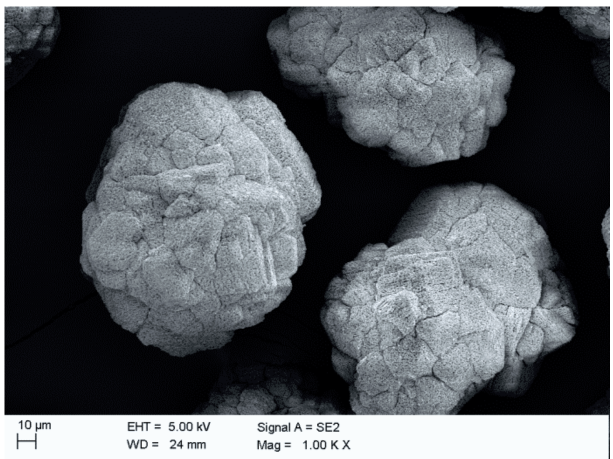
Mean mass concentration of elements, wt.%							
Si	Fe	Cu	Mn	Zn	Ti	Others	Al
12	≤0.55	≤0.05	≤0.35	≤0.15	≤0.2	≤0.15	Balance

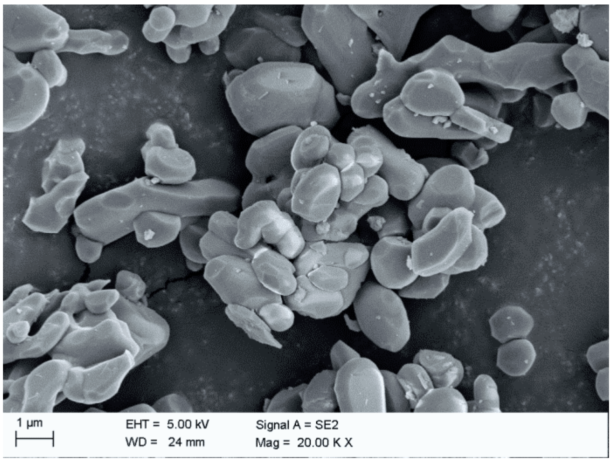
Observation of fractures structure of ceramic preforms manufactured by sintering Al_2O_3 Alcoa Cl 2500 powder was carried out in the scanning electron microscope Zeiss Supra 35. Investigations of tribological properties of composite materials and the matrix material were made using a CSM Instruments Tribometer by the pin-on-disc method. As the counter sample, ceramic balls diameter of 5.56 mm was used. Test was carried out at a constant load of 10 N. The linear speed of the samples was 3 cm/s, and wear covered area with a radius of 7 mm, while road friction is 100m. The friction coefficient was recorded at a frequency of 2 Hz. After finishing the test, traces were examined using profilometer Taylor-Hubson Sutronic 25 cooperating with tribometer. Application of software TRIBOX allowed determining cross-sectional area and the calculated volume of wear caused cavities. In addition, wear traces were investigated by light and confocal microscopy.

3. Experimental results and their discussion

Examination of the structure of as delivered Al_2O_3 Alcoa Cl 2500 powder and powder after the milling process made in the scanning electron microscope (Fig. 2) allow concluding that during the grinding process agglomerations of ceramic particles were broken up.

a)

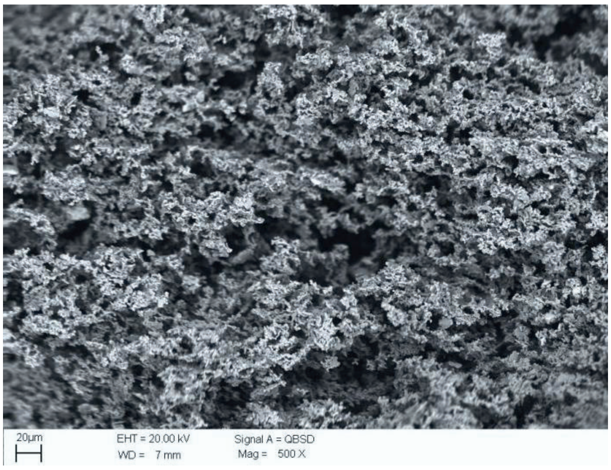




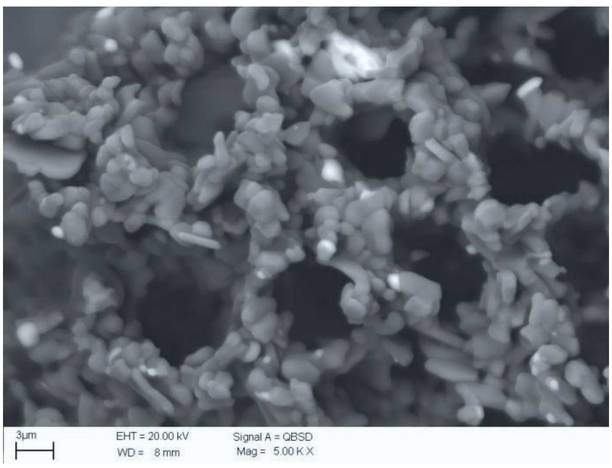
b)

Fig. 2. Structure of Al_2O_3 Alcoa Cl 2500 powder: a) as delivered magnification 1000x, b) after the milling process, magnification 20,000x

Observation of structure of the fractures of the ceramic preforms manufactured by sintering Al_2O_3 Alcoa Cl 2500 powder made in the scanning electron microscope (Fig. 3), allowed to reveal two basic types of pores. The first larger were formed as a result of degradation carbon fibres, and the second smaller occurred around the single ceramic particles, and resulted in deliberate pre-compaction absence (use of higher compaction pressure and the higher sintering temperature).



a)



b)

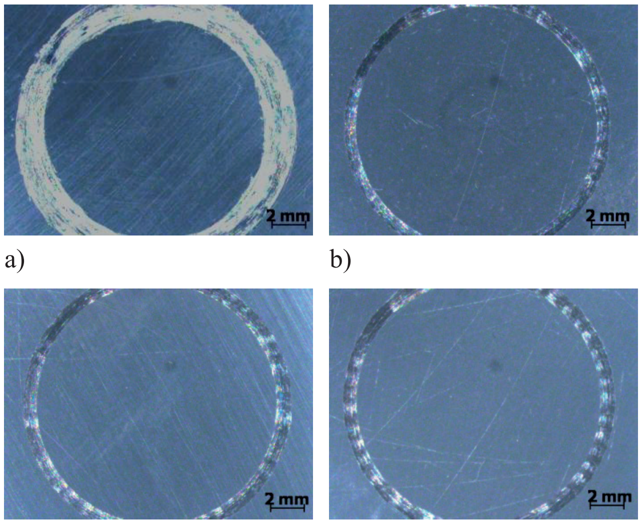
Fig. 3. Microstructure of ceramic preform fracture a) magnification 500x, b) magnification 5000x

Based on wear and abrasive resistance examinations of manufactured composite materials and matrix, the average friction coefficient was established. As a measure of wear of tested materials, wear traces volume was assumed, calculated on the base of profiles. The results are summarised in Table 2, while Fig. 4 shows the structure of wear traces observed in the stereoscopic microscope.

TABLE 2

Tribological properties of composite materials and matrix

Content of ceramic phase %	Friction coefficient	Wear trace volume [mm^3]
EN AC – AlSi12	0.44	7.26
20	0.46	0.43
24	0.50	0.54
33	0.60	0.61

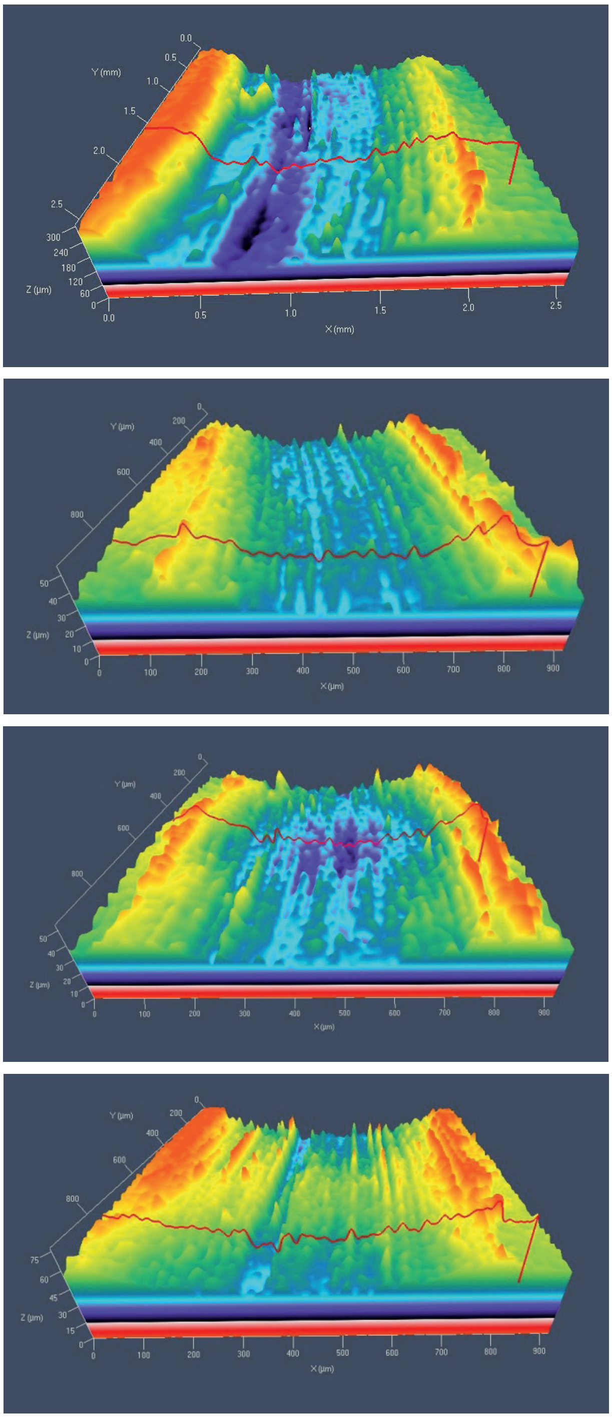


a) b) c) d)

Fig. 4. Structure of wear traces: a) matrix EN AC - AlSi12, b) composite material with 20% content of ceramic phase, c) composite material with 24% content of ceramic phase, d) composite material with 33% content of ceramic phase

All analysed materials evenly wear out was evidenced by their wear traces (Fig. 4) The EN AC - AlSi12 alloy matrix of composite materials shows the smallest value of friction coefficient 0.44. Introduction to it hard Al_2O_3 particles with sharp edges (Fig. 2b) increases the friction coefficient to 0.46-0.60. This happens as a result of protruding from matrix the ceramic particles, resulting in loosing real contact area and increases the local stresses in the friction zone. The friction coefficient increases with an increase of content of the ceramic phase in composite materials.

Developed ceramic materials have much higher wear resistance than the matrix. Hard Al_2O_3 particles combined with matrix protect it against wear, but after chipping remaining even for a short time between couple friction act as abrasive and destroy their surfaces. Thus, profiles of wear of composite material (Figs. 5 b-d) show the numerous grooves parallel to the friction direction. The wear track structure of the matrix is smoother (Fig. 5 a). This phenomenon explains observed increase in wear of the materials with increasing content of ceramic phase.



a)

b)

c)

d)

Fig. 5. Profiles of wear traces: a) matrix EN AC - AlSi12, b) composite material with 20% content of ceramic phase, c) composite material with 24% content of ceramic phase, d) composite material with 33% content of ceramic phase

4. Conclusion

- An important step in the preparation of sintered porous preforms is powder pre-milling, since particles agglomerates formed during their synthesis are broken up, what reduces the occurrence of closed pores in the final material.
- Using carbon fibres results in a high purity of the process, because they degrade mainly to CO_2 and sintering process does not require pyrolysis.
- Developed composite materials produced by pressure infiltration of porous ceramic preforms based on Al_2O_3 particles have much better wear resistance than the matrix, which is a casting aluminium alloy EN AC - AlSi12.
- Size of the damage caused by the removal of reinforcement from the matrix during friction process in, largely on its shape. Least of all benefits are hard and sharp Al_2O_3 particles, which staying even for a short time between acting element destroy their surface.
- It was found that the developed technology of manufacturing composite material with EN AC - AlSi12 alloy matrix reinforced with Al_2O_3 particles consisting the infiltration of a ceramic preform by liquid aluminium alloy ensure necessary structure and much-improved wear resistance in relation to the matrix and therefore may find practical application.

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