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].

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

---

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

---

* Corresponding author: marek.kremzer@polsl.pl
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 Al₂O₃.

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 Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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 Al₂O₃ 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. Near eutectic casting aluminium alloy EN AC - ALSi12 was used as a matrix, while as reinforcement the Al₂O₃ 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 CO₂, 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.
Observation of structure of the fractures of the ceramic preforms manufactured by sintering $\text{Al}_2\text{O}_3$ Alcoa Cl 2500 powder, 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).

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

<table>
<thead>
<tr>
<th>Content of ceramic phase %</th>
<th>Friction coefficient</th>
<th>Wear trace volume [mm$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{EN AC} – \text{AlSi12}$</td>
<td>0.44</td>
<td>7.26</td>
</tr>
<tr>
<td>20</td>
<td>0.46</td>
<td>0.43</td>
</tr>
<tr>
<td>24</td>
<td>0.50</td>
<td>0.54</td>
</tr>
<tr>
<td>33</td>
<td>0.60</td>
<td>0.61</td>
</tr>
</tbody>
</table>

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 $\text{Al}_2\text{O}_3$ 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 $\text{Al}_2\text{O}_3$ 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.
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 CO₂ and sintering process does not require pyrolysis.
- Developed composite materials produced by pressure infiltration of porous ceramic preforms based on Al₂O₃ 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 is, largely on its shape. Least of all benefits are hard and sharp Al₂O₃ 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 Al₂O₃ 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.

Acknowledgements

This publication was financed by the Ministry of Science and Higher Education of Poland as the statutory financial grant of the Faculty of Mechanical Engineering SUT.

REFERENCES
