

Composites applied for pistons

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Abstract

In the article the possibility of application the composite materials in casts into metal mould to form the pistons for compressors have been presented. In cooperation with “Złotecki” company was undertaken the test of casting in productive conditions the aluminium alloy matrix composites reinforced with silicon carbide particles and composites reinforced with the mixture of the silicon carbide (SiC) and amorphous glass carbon particles.

On the basis microstructural investigations were affirmed the uniformly distribution of reinforcing particles on the cross section of studied pistons. Realized technological tests confirmed the possibility of formation composite pistons with one kind of reinforcing phase and heterophase reinforcement from utilization the technology of mould casting.

Key words: AMMCs, mould casting, ceramic particles, microstructure, hardness.

1. Introduction

Compared to traditional aluminium alloys, aluminium alloy matrix composites reinforced with ceramic particles have better stiffness, creep resistance and wear resistance. They find application first of all in the automotive industry. The construction of vehicles is a discipline in which both economical and ecological aspects are of essential importance. One of the design criteria is the endeavour to reduce the structure's weight and thus, to reduce fuel consumption. Composites produced at an industrial scale (e.g. Duralcan of Alcoa International, Safil – 3M) are used for manufacturing of cylinder sleeves, pistons, brake drums and disks [1-3]. Research on the prospects for composite materials development in combustion engines, especially regarding the materials intended for pistons, was undertaken also in Polish research and scientific centres [4-9]. The today's interest in AMMCs results from a number of their creative properties, which can be designed through a proper selection of reinforcing components and technological parameters. The modern material intended for pistons should be first of all characterized by:

- ◆ proper thermal expansion and conductivity;
- ◆ resistance to thermal shock;
- ◆ good tribological properties;

- ◆ advantageous mechanical properties, in particular fatigue strength;
- ◆ appropriate hardness;
- ◆ low density and capacity for vibration damping.

Composite pistons are most often obtained through squeeze casting. They are made from aluminium alloys reinforced with ceramic particles throughout the product's volume or locally. In case of local reinforcement, ceramic inserts or pre moulds made of whiskers or short fibres are used. For the manufacture of locally reinforced pistons, metal pressure infiltration of a preheated pre mould is applied [4,5].

However, implementation of new materials into production frequently meets barriers connected with high costs of the existing process lines adaptation or necessitates the installation of new facilities in a production line. Since composites belong to materials difficult to machine, they require a special selection of machining tools. From this point of view, the liquid-phase technologies of composites production and their forming via casting methods belong to the cheapest manufacturing methods and seem to be easier to implement [6,7,10,11]. Obtaining a stable composite suspension requires meeting the conditions in which the ceramics will be wetted through liquid metal, thus enabling the achieving of a permanent bonding on the reinforcing

phase/matrix boundary. In the composites' production process via mechanical stirring, the following factors are important: matrix alloy's preparation (refining, alloy's composition modification), ceramic particles' preparation (chemical preparation, thermal treatment) and the intensity of stirring the suspension. The homogenization conditions are decisive as regards a uniform distribution of the ceramic reinforcement throughout the liquid metal's volume, which translates to the composite material structure formed in the casting process [12-14]. Some disadvantageous phenomena connected with ceramic particles' sedimentation, floatation or agglomeration, may result in changed castability of a suspension and make it difficult, or in some cases even make it impossible, to form the product via casting methods. The above-mentioned phenomena also affect composite material's solidification and crystallization. Moreover, they are the main reason for porosity occurrence in a cast, which has an adverse effect on mechanical properties, including reduced corrosion resistance of a composite [14-16].

2. Experimental studies

At attempt of casting AMMC materials in manufacturing conditions was undertaken in a cooperation with the company Złotecki Sp. z o.o. As a result of the experiment, 2 composite groups with AlSi12CuMgNi alloy matrixes were produced. One group includes a material reinforced with silicon carbide particles with a 15% weight fraction and grain size of 25 μm . The other group is represented by heterophase composites reinforced with a 15% mixture of silicon carbide (25 μm) and amorphous glassy carbon particles (100 μm).

The composite material was prepared via stirring method in the laboratory of the Silesian University of Technology in Katowice. The process was conducted at two stages. Before the introduction of ceramic reinforcement into the matrix, the alloy's composition was modified by adding 2% Mg and 0.02% Sr. Ceramic particles were soaked at a temperature of 350°C, and next, introduced into the liquid metal at 720°C. At the second stage, the suspensions produced were placed in a hermetic chamber which facilitates degassing and homogenization under reduced pressure conditions. After air was pumped out of the chamber, the homogenization process was conducted at a temperature of 720°C. The suspensions were stirred for 30 minutes at reduced pressure (900 hPa). At the final 15-minute phase of the process, the pressure was reduced to 200 hPa. A scheme of the laboratory stand is presented in articles [6,7]. The composite suspensions, both homo- (AlSi12CuMgNi/SiC_p15%) and heterophase (AlSi12CuMgNi/SiC_p+Cg), were cast into graphite moulds, thus obtaining 2.5 kg ingots.

The company Złotecki Sp. z o.o. made a gravity die available for the experiment. The five-part mould is used for manual casting of pistons, 65 mm in diameter, for air compressors. When planning the experiment, it was assumed that in the first phase, all technological parameters of the casting process will be assumed according to the Złotecki company's standards. The pouring temperature ($T_z = 720^\circ\text{C}$) was assumed in accordance with the authors' earlier investigations [12-14].

After ingots' remelting, the composite suspensions were subjected to stirring for 30 minutes. Gravity die casting was

performed by an authorized employee of the company. A dozen or so casts were made in the experimental cycle, six in each material group. All casts very accurately showed the mould's shape and the preliminary evaluation of walls' thicknesses and curvatures was successful (Fig. 1).

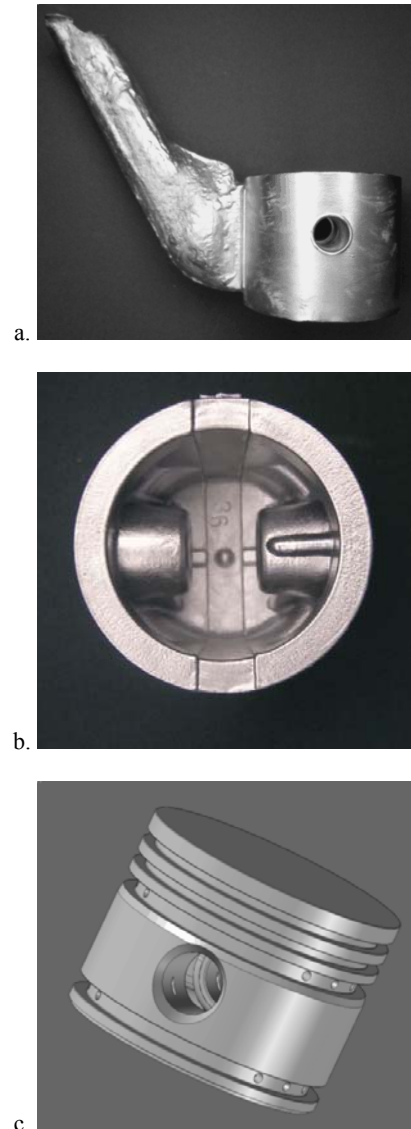


Fig. 1. Composite' pistons: a) cast piston with mould feeder, b) bottom part of piston, c) view of piston after machining treatment, [6].

Figure 1a presents a selected representative cast (AlSi12CuMgNi+SiC) along with the casting system and a view of the piston's lower part (Fig. 1b). Figure 3b presents the selected piston after machining treatment.

3. Microstructure and hardness of the pistons produced

The produced composite pistons were cut and transverse microsections were prepared. Figure 2 shows a section of a silicon carbide reinforced composite piston. Next, the microsections were subjected to microstructural observation on an optical microscope. Some typical photographs of the structure, taken on the composite pistons' cross-sections, are presented in Figs. 3 and 4. Observation of pistons' inner structure was conducted in two areas: from the side of the casting system and in the area opposite the casting system.

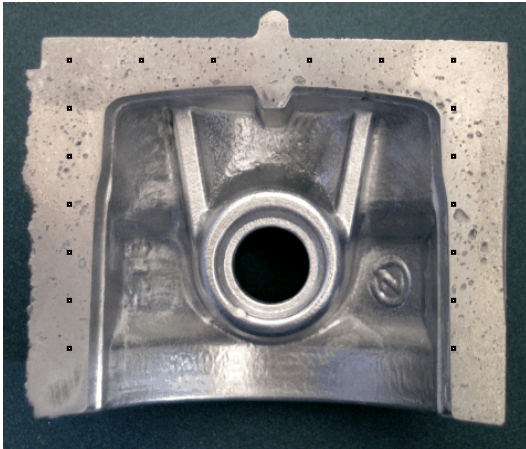


Fig. 2. Cross section of AlSi12CuMgNi/SiC_p composite cast piston.

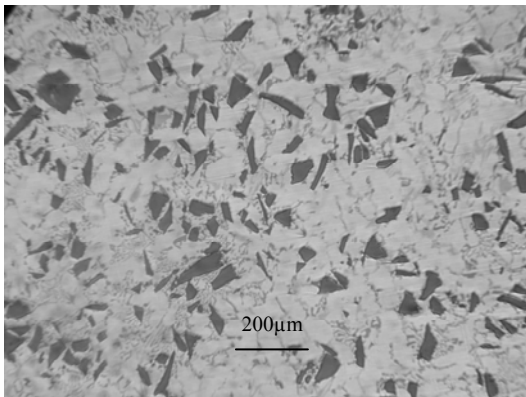
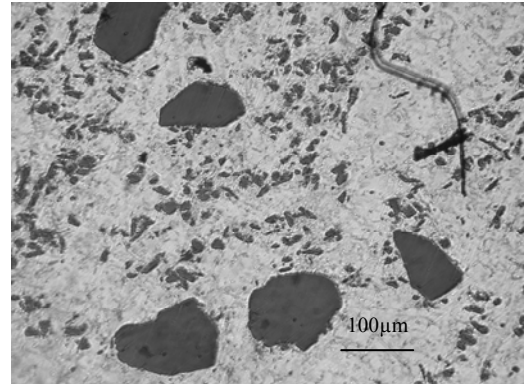


Fig. 3. Microstructure of AlSi12CuMgNi-SiC_p composite piston, area opposite to the casting system.

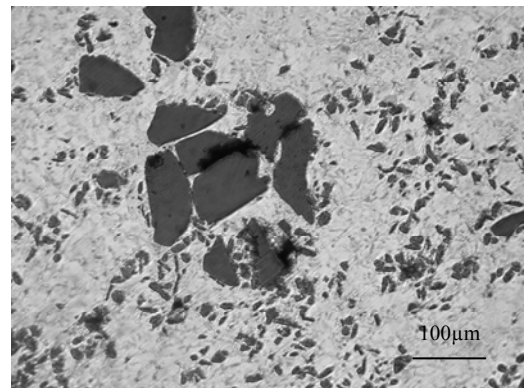
Based on the microstructural observations, it was found that the reinforcing particles' distribution of both the silicon carbide (Fig. 3) and the SiC+Cg mixture (Fig. 4) in the matrix on the investigated pistons' section, was uniform. However, porosity was

also found in the structure, especially in the casting system regions.

The pores and particles' agglomerates are concentrated on pistons' internal walls, whereas the external areas, as well as the structure of regions on the other side of the casting system, show insignificant porosity with rare voids around the uniformly distributed ceramic particles. The described unfavourable porosity phenomenon should be linked to both the technological parameters applied during the casting process and the matrix solidification and crystallization processes.



a.



b.

Fig. 4. Microstructure of AlSi12CuMgNi/SiC_p+Cg heterophase piston: a) area opposite to the casting system, b) casting system regions.

The research of the hardness was carried out on the Brinell testing machine. A steel ball was used about the 5mm diameter and load equal 250N. Examinations were made in eighteen measuring points on a cross section of pistons visible on the Figure 2. Gotten results were presented in the form of columnar diagrams in Figure 5. It was found that the higher hardness and the more uniformity distribution of hardness on the piston's cross sections has heterophase composite (Fig. 5b). Differences in the measured values of hardness may indicate an more uniform distribution of reinforcing particles and with presence of the second phase in aluminium matrix.

4. Conclusion

The performed technological tests have corroborated the possibility of forming composite pistons with both homo- and heterophase reinforcement, in the gravity die casting process. The above-discussed unfavourable phenomenon of porosity, which was identified in pistons' casting regions, poses a serious problem to be solved in the course of further research on optimization of parameters of the cast production technology. The scope of further studies will include manufacturing of composite pistons based on composites reinforced with aluminium oxide particles (Al_2O_3) and with the application of heterophase reinforcement of the Al_2O_3 -Cg type.

For an in-depth evaluation of the possibility of applying composite materials for the production of air-compressor pistons, further studies are necessary to identify the capacities for mechanical processing on automatic lathes, as well as tests regarding the real operational conditions of pistons working in a friction couple with the cylinder sleeve.

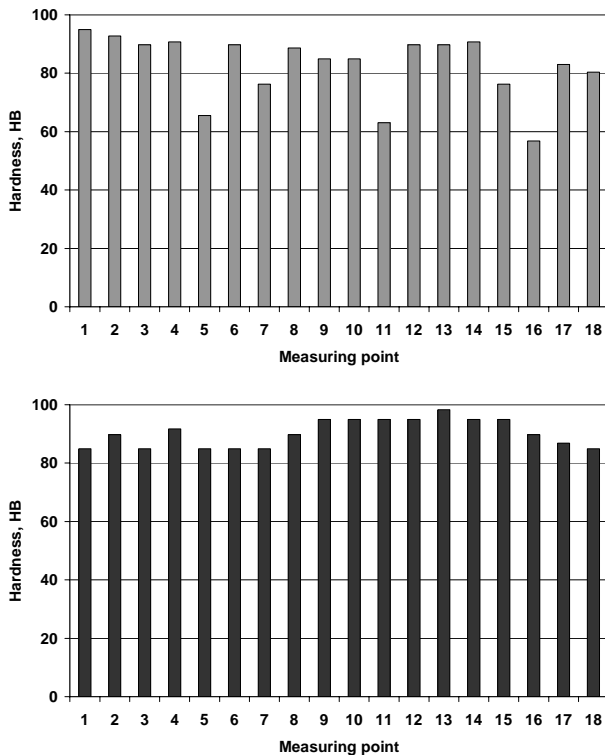


Fig. 5. Distribution of Brinell' hardness on the cross section of pistons testing: a) hardness of AlSi12CuMgNi -SiC_p piston, b) hardness of AlSi12CuMgNi/SiC_p+Cg piston.

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