

## CAST HYBRID COMPOSITES DESIGNATED FOR AIR COMPRESSOR PISTONS

The main purpose of the investigations was to develop the phase composition of the composite assuming that the component selection criterion will be the formability of piston work surfaces during the machining. Wear resistance under the friction conditions was assumed as the additional parameter for the assessment of composite material. In the study were used AlSi7Mg/SiC+Cg and AlSi7Mg/SiC+GR hybrid composites prepared by the stir casting method.

*Keywords:* hybrid aluminium composites, glassy carbon, graphite particles, mould casting, machining

### 1. Introduction

Aluminium matrix composites have been indicated as the materials having the large potential for innovation, as evidenced by increased use of these materials in sectors such as the aircraft or automotive industries. One of the first examples of applications of aluminium matrix composite implemented for production was the piston with a composite insert reinforced with Saffil fibres, manufactured on an industrial scale by the squeeze casting method [1]. Since last 10 years, only according to the data presented by Elsevier and Springer publishing companies, more than 500 articles concerning the possibility of manufacturing Al matrix composites obtained by casting methods are published every year. Manufactured on an industrial scale are composite elements operating under high friction loads, such as pistons, drums and brake discs [2]. Another field of applications of aluminium matrix composites is the electrical engineering where, above all, the dimensional stability of radiators working at elevated temperatures is utilised. The main technologies for fabrication of these materials are based on the powder metallurgy [3,4], porous ceramic preform infiltration [5,6], pressure die-casting [7] and squeeze casting methods [8,9]. However, the manufacturing costs, and first of all the costs of machining, are still indicated as important limitations in the implementation of composites on a wider scale [10-12].

One of the main advantages of composites is the possibility to obtain the appropriate material properties by forming its structure in the manufacturing process. The selection of the matrix material as well as the type, size and volume fraction of the reinforcing phases and the selection of technological parameters allow obtaining materials with properties exceeding those of a non-reinforced matrix material.

The works conducted for many years at the Metal Composites Laboratory of the Faculty of Materials Engineering

and Metallurgy of the Silesian University of Technology have resulted in the development of the suspension method, which allows the fabrication of composites on a semi-technical scale and forming products in the die-casting process under industrial conditions [13-15].

### 2. Suspension method for fabrication of composites

An important factor that decides about the possibility to produce a stable composite suspension is to provide conditions under which the ceramic phase will be wetted by liquid metal. To obtain a permanent joint at the reinforcing phase and matrix interface, it is required to prepare liquid alloy of the matrix, make a treatment of ceramic particles and provide the appropriate suspension homogenisation conditions.

The composite production process by the suspension method is realised in the autoclave furnace PTA 200/PrG with moving graphite stirrer system. The airtight furnace chamber allows the protective atmosphere to be obtained when melting the charge and the reduced pressure to be produced when homogenising the suspension.

The composite production procedure starts with refining and modification of chemical composition of the matrix liquid alloy. The refining is carried out by bubbling using argon, which flows through the rotating graphite stirrer submerged under the liquid metal level. After removal of impurities that collect on the metal surface, the modifiers in the form of AlMg and AlSr master alloys are introduced into the matrix. The addition of modifiers such as magnesium and strontium affects not only the matrix structure in the casting, but also changes the properties of alloy in liquid state. The change in surface tension and disintegration of the oxide film are favourable for ceramics to be moistened by liquid metal. Another stage is based on the stir-casting method where on the spinning liquid metal surface are introduced the previously

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preheated ceramic particles. Then, the produced composite suspension is put to homogenisation and degassing under reduced pressure conditions.

**3. Produced materials and they properties**

As a part of the industrial tests carried out with cooperation engine pistons factory (Złotecki Sp. z o. o.), the AlSi7Mg hybrid composites were produced. The SiC F 360 (Polmineral) particles with granularity of 20-30 µm and glassy carbon 4208GCP (SPI Supplies) with granularity of 40-80 µm were used as the first hybrid reinforcing mixture (5 % vol. SiC and 2 % vol. C<sub>g</sub>), and SiC SIKA SABR P (Saint Gobain) with granularity of 40 µm and spherical graphite powder (American Elements) with 15-40 µm particle size were used as the second one (10% vol. SiC and 10% vol. GR).

The base AlSi7Mg matrix alloy was melted at 720°C, and then put to one-hour refining with argon (Ar 5.0 – Messer Polska, flow of 5 l/min) that flowed through the rotating stirrer submerged under the liquid metal level. After removal of impurities that form slag on the metal surface, the modifiers in the form of AlMg25 and AlSr10 master alloys made by IMN OML in Skawina (the Institute of Non-Ferrous Metals in Gliwice, Light Metals Division in Skawina) were introduced into the matrix. The amounts of modifiers were selected so that the weight percentage of magnesium in alloy can be increased up to 2% and of strontium up to 0.03% (Tab. 1). After the introduction of master alloys, the modified matrix alloy was mixed under reduced pressure conditions (50 hPa) at 720°C for 1 hour.

TABLE 1  
Chemical composition of EN AlSi7Mg aluminium alloys

	Al	Si	Fe	Cu	Mn	Mg	Sr
AlSi7Mg*	93.7	5.03	0.429	0.0116	0.131	0.378	0.0007
AlSi7Mg**	91.6	4.81	0.480	0.0107	0.134	2.300	0.0329

\* Alloy composition tested by using the mass spectrometer (Foundry Master)

\*\* Alloy composition after modification by Mg and Sr tested by using the mass spectrometer (Foundry Master)

Then the working chamber of the furnace was filled

with argon to produce the protective atmosphere during the introduction of particles. The ceramic particles were initially held at 700°C for 24 hours, and before their introduction into liquid metal they were held at 300°C for 2 hours. The particles were introduced onto the vortex surface of metal in the amount of 200 g/min.

The homogenisation and degassing of the suspension was carried out under reduced pressure conditions (50hPa) in argon.

Semi-finished pistons were cast into the metal mould with five-section internal core and nitride coating mounted to the casting machine GM110. Structure of both hybrid composites (AlSi7Mg2Sr003/SiC+C<sub>g</sub> and AlSi7Mg2Sr003/SiC+GR) in the cast condition is shown in figure 1.

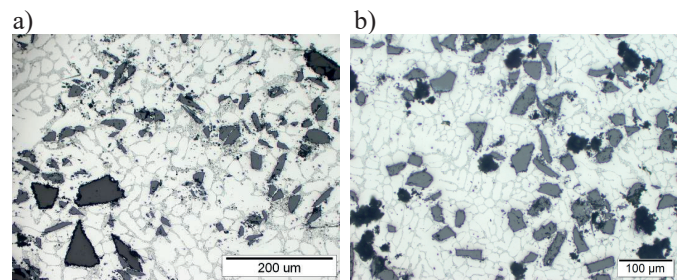


Fig. 1. The structure of hybrid composites: a) AlSi7Mg2Sr003/SiC+C<sub>g</sub>, b) AlSi7Mg2Sr003/SiC+GR, [16]

**3.1. Machining**

The piston work surface forming process consists of the following:

- isolation of the power supply system and feedhead,
- pre-machining of the piston shell,
- preparation of the machining datum surface,
- pre-machining of the pin holes,
- drilling of holes to lubricate the piston shell,
- post-finishing of the piston shell,
- medium machining of the pin holes.

For a piston of 65 mm in diameter, the manufacturing accuracy check includes 16 measuring points with acceptable dimensional tolerance of +0.02 mm. The view of the mould cast semi-finished piston and piston after surface forming

TABLE 2  
Comparison of the durability the polycrystalline diamond blades (PCD) after machining

Sample	Tool	Cutting condition			Blade durability		Roughness of surface
		cutting speed	feed rate	depth of cut	deburbing criterion		
		vc [m/min]	f [mm/obr]	ap [mm]	VB [mm]	T [min]	
AlSi7Mg2Sr003	DCMW	500	0,10	0,5	0,07	40,5	0,8
AlSi7Mg2Sr003/ SiC 5% + C <sub>g</sub> 2%	DCMW	500	0,10	0,5	0,30	17,0	1
AlSi7Mg2Sr003/ SiC 10% + GR 10%	DCMW	500	0,10	0,5	0,30	5,3	0,8

process illustrated figure 2.

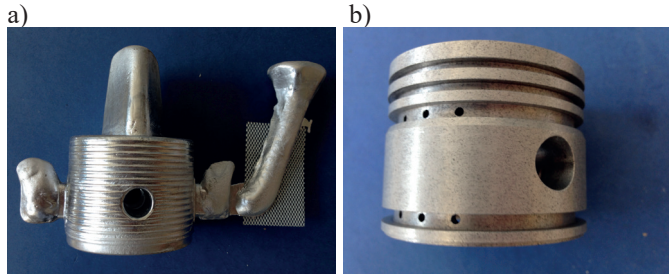


Fig. 2. The view of: a) the mould cast semi-finished piston, b) piston after surface forming process

To assess the machinability properties of the produced materials, the cutting tests were carried out at the machining centre NL2000 SY in the Institute of Advanced Manufacturing Technology in Cracow.

The machining tests were carried out using polycrystalline diamond tools with a rhombus cross-section and an angle  $\epsilon_r = 55^\circ$  (D), plate clearance angle of  $7^\circ$  (C), dimensional tolerance in (M) class, partially cylindrical mounting countersunk hole on one surface ( $40\text{--}60^\circ$ ) and without chip breaker.

The nature and size of the wear on the flank or corner face were checked (VBB max and VBC parameters to PN-ISO 3685:1996). Roughness of the machined surface ( $R_a$  parameter) was also measured with the profile measurement gauge Hommel Tester T1000E (Table 2). The limit service life of the blade was assumed to be its service time after which the wear parameter VBB or VBC reaches 0.3 mm. The tool wear nature is presented in Fig. 3.

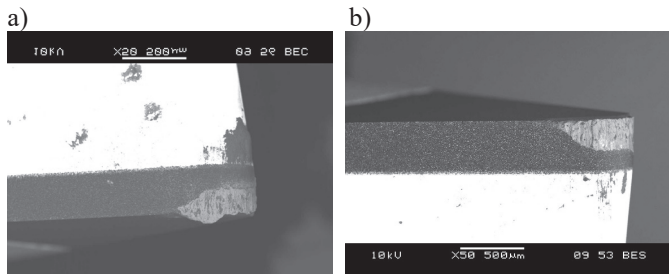


Fig. 3. SEM image of surface polycrystalline diamond blades (PCD): a) worn by formation of accumulations by AISi7Mg2Sr003 / SiC +  $C_g$ , b) worn by formation of accumulations by AISi7Mg2Sr003 / SiC + GR

### 3.2. Tribological tests

The tribological tests using the versatile mechanical tester CETR UMT-2M in the mandrel-disc configuration were carried out at the Institute of Advanced Manufacturing Technology in Cracow and the abrasion wear tests using the Taber Rotary Abraser tester were made at the Light Metals Division of the Institute of Non-Ferrous Metals in Skawina [17].

In the pin on disc configuration, the test sample was a cast iron pin with diameter of 5 mm, loaded with 2 N. The counter-test sample was composite discs. The tests were carried out with friction radius of 10 mm and friction linear speed of 6000 mm/min at a distance of 500 m. Fig. 4 shows changes in

coefficient of friction in time.

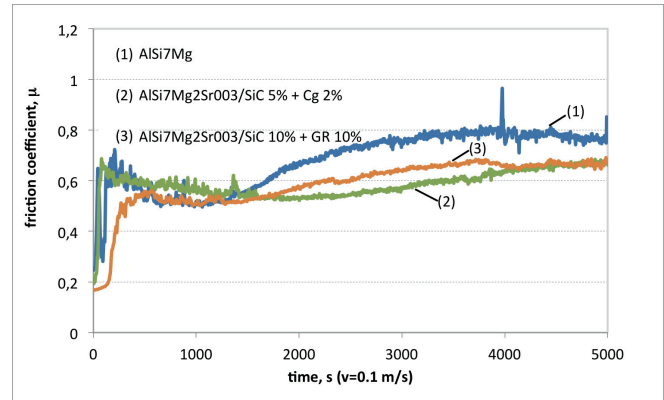


Fig. 4. The diagram of changes the coefficient of friction at the time of composite materials and matrix alloy

The wear tests consisting of 1000 cycles were carried out with the Taber Rotary Abraser tester using the abrasion wheels H18, with test load of 500 g, suction force of 70% and rotational speed of 60 rev/min [16]. The average test piece weight loss is presented in Fig. 5.

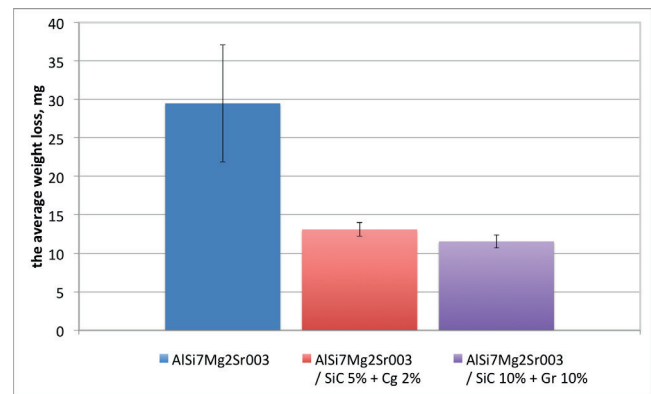


Fig. 5. The average loss of mass in the abrasive wear test

## 4. Summary

The performance tests with regard to casting of a series of composite pistons confirmed the possibility of using the suspension method for fabrication of AISi matrix composites reinforced with both hybrid mixture SiC+ $C_g$  particles and the mixture of SiC+GR on a semi-technical scale. The assessment of machinability properties indicates the particular conditions of composite material machining (machining with impacts) during which the cutting tool comes across the ductile matrix and hard ceramic particles. The rolling tests of the composite materials and non-reinforced matrix material with speed of 500 m/min and travel of 0.10 mm/rev. reveal significant wear of the cutting tools in case of composite machining. For AISi7Mg2Sr003/SiC+GR material, the adopted deburring criterion  $VB=0.3\text{mm}$  was reached after 5.3 minutes of tool operation. For AISi7Mg2Sr003/SiC+ $C_g$  composite, the deburring criterion  $VB=0.3\text{mm}$  was reached after 17 minutes of tool operation. In both case, the formation of deposits on the cutting insert was observed. Favorable surface quality achieved for

AlSi7Mg2Sr003/SiC+GR hybrid composite ( $R_a=0,8$  similar to unreinforced matrix material). The tribological tests in the pin on disc configuration confirmed the advantageous effect of hybrid reinforcing on the reduction of the coefficient of friction compared to unreinforced matrix material. In the abrasion wear test, lower wear of the AlSi7Mg2Sr003/SiC+GR composite test pieces compared to that of the AlSi7Mg2Sr003/SiC+C<sub>g</sub> composite was recorded.

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