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Die-cast heterophase composites with AlSi13Mg1CuNi matrix

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Abstract

On the basis of the performed tests, an advantageous interaction of glassy carbon particles in a couple consisting of a heterophase composite and a spheroidal cast iron has been corroborated. It was found that, the presence of glassy carbon in the heterophase composite (SiC+C) affects the stabilization of the friction coefficient value as a function of the friction distance and reduces the intensity of the wearing-in stage of the interacting surfaces. Both a decrease of the friction coefficient and the wear of the heterophase composites may be connected with the carbon particles' chipping effect and the deposition of its fragments on the surface of the interacting components of the friction couple, which forms a kind of a solid lubricating agent in the system. This should allow applying of this material to the composite piston - cylinder sleeve system in piston air-compressors. Further works will concern the selection of the matrix alloy composition with the purpose of reducing the phenomenon of particles chipping during machining. It seems that one of the possibilities is the application of a more plastic matrix and optimizing the fraction of reinforcing phases and their gradient distribution in the casting.

Słowa kluczowe: cast composites, heterophase reinforcement, composite pistons, dry friction.

1. Introduction

Aluminium matrix composites (AlMCs) have been referred to as "materials of the future" for over 30 years. Considerable financial outlays for research and implementation conducted in the 1980s and 1990s resulted in the development of a production technology of materials characterised by higher strength, better stiffness, lower density, increased high-temperature strength, a stable thermal expansion coefficient and increased resistance to wear during friction in comparison to non-reinforced matrix alloys. As a result of those works, the Duralcan company, among others, started production of composites with alloy matrix reinforced with SiC particles, with the capacity of 113,000,000 kg a year. However, according to data published in the reports of Business Communications Company Inc. (www.bccresearch.com), the global demand for metal matrix composites will reach 5.9m kg in the year 2013, and the main consumers will be the land transport (mainly the automotive industry) and the electronics industry, where a 5% annual growth of composite usage in modern constructions is planned. These findings change the former optimistic forecasts which suggested a 14% annual growth of the composite material market in the years 1999-2004 [1-4].

In spite of successful implementation of the production of composite pistons in Toyota diesel engines or the use of composites in the production of drive shafts by GM in the Corvette model, these materials have not come into widespread use due to considerable costs connected with starting the production [3]. Another problem is the lack of a complete description of the properties of composite materials, especially data for modelling structural components and production processes. Currently, there is a recurrence of interest in aluminium matrix composites, particularly in the automotive industry. Works are conducted concerning light engineering materials which will allow a decrease of the structure mass, which in turn will contribute to reducing the consumption of fuel and enhancing the efficiency of vehicles. [4]. It is estimated that 75% of fuel consumption by the engine is connected with the mass of the vehicle, whereas decreasing the mass of spinning parts by 1 kg allows to decrease the mass of elements responsible for suspension and balance by 7 kg. Owing to their high resistance to wear during friction, composites can be used for pistons, connecting rods, cylinder sleeves and brake discs. Another application of aluminium matrix composites is in the electronics industry, where the dimensional stability and capacity to absorb and remove heat is used in radiators. Therefore, numerous research centres conduct research to create efficient and cheaper methods of production of metal composites [5-7]. The main problems are still: a reduction of production costs, developing methods of composite material and end product quality assessment, standardisation, and development of recycling and mechanical processing methods.

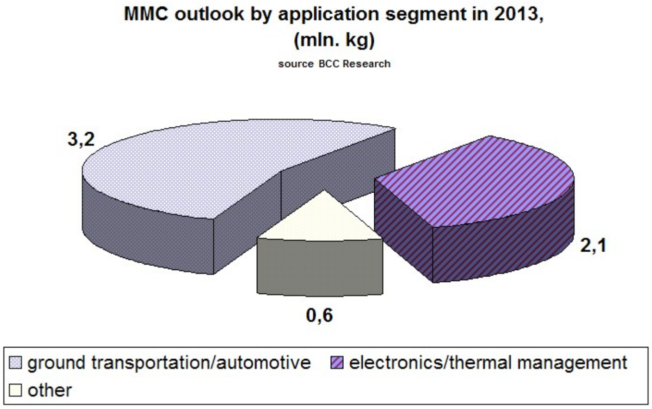

Fig. 1. Forecast of MMC application in industry segment in 2013, source BCC Research.

2. Heterophase composites

The application of multiphase reinforcement for strengthening aluminium alloys is a new material solution which allows, to a large degree, to expand the capacity for designing and diversifying product properties, especially the mechanical and tribological ones. Composites of this type were used in the production of cylinder sleeves in the engines of Honda Prelude 2.3 and Toyota Celica. The application of a premould with a 12% share of Al_2O_3 fibres and a 9% share of carbon fibres helped to reduce the engine block mass, improve the cooling conditions and decrease wear in the friction conditions [3]. Composite production technologies, based on liquid-phase methods, and the shaping of products by means of casting methods, belong to the cheapest production methods. In comparison with methods which use premould infiltration techniques, casting methods are several hundred times cheaper. Some issues connected with heat treatment of the composite material, problems with shaping end products and their further finishing still pose certain restrictions on the widespread implementation of these methods into the production process. Machining, which requires a special selection of machining tools, is particularly expensive.

Application of a suspension method for the production of composites with heterophase reinforcement may turn out to be a new material and technological solution. Research works carried out at the Faculty of Materials Engineering and Metallurgy, the Silesian University of Technology, under Projects (PBZ/KBN/114/T08/2008; KBN 3 T08D 024 28) have confirmed good casting properties of heterophase composite suspensions [7-9]. The application of SiC and glassy carbon particles enables stabilizing the friction coefficient and, most of all, reducing the wear of the friction partner [10]. These properties may be used in a tribological piston-cylinder system, from which dimensional stability, strength and durability are required.

The aim of research carried out under the research and development project PBR N RO7 001106 is to develop a comprehensive technology of production of composite pistons with heterophase reinforcement. There are plans to transfer the production procedure of composite suspensions , developed at a laboratory scale by the authors of the Project, to a semi-commercial scale of production, so as to enable die-casting of air-compressor pistons in industrial conditions. To achieve this aim, a new material solution and technology have been proposed, allowing to present, as an outcome of the project, a technological procedure which allows the production of a composite suspension in the amount of ca. 50 kg of melt at a time. This should enable fabrication of a prototype batch of composite pistons in industrial conditions, based on the die-casting method. The possibility of full finishing of the piston, based on machining centres, has been assumed to be the evaluation method regarding correctness of the project assumptions.

3. Experimental researches

In a collaboration with Złotecki Sp. z o.o. company, preliminary casting tests were undertaken in the production conditions of composites with the AlSi13Mg1CuNi matrix, reinforced by means of silicon carbide particles and a mixture of silicon carbide and glassy carbon particles. The composite material was prepared via suspension 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 composition was modified by adding 2% Mg and 0.03% Sr. Ceramic particles were soaked at a temperature of 350ºC and next, introduced into the liquid metal at 720ºC. At the second stage, the crucible with the composite suspension was placed in a hermetic chamber which facilitates degassing and homogenization under reduced pressure conditions [7,8]. This way, 2.5 kg of ingot was obtained, which then was remelted and stirred for 30 minutes in the production conditions of the casting house. At this stage of tests, series consisting of five composite pistons each, with SiC particles and heterophase reinforcement SiC+C, were cast. The evaluation of the pistons cast was based on the wear tests under technically dry friction conditions and on the machining of the surface. The geometry of the piston surface was shaped in accordance with production requirements for a standard air-compressor piston. The piston surface after machining and the composite microstructure after casting are presented in Figure 2.

The structure analysis of the produced composite pistons has confirmed a uniform distribution of reinforcing particles in the matrix and a slight porosity in the casting. Despite a good quality of the composite material and a durable connection on the particle-matrix boundary, accompanied by the formation of spinel AlMgO [9], the machining of the pistons revealed numerous areas with the reinforcement particles chipped off from the piston skirt surface. The likely cause of this phenomenon is the interaction of a hard turning tool with the brittle composite material (hard ceramic particles – brittle matrix AlSi13Mg1CuNi). To a large degree, it makes the machining and the shaping of the correct geometry of the piston working surface difficult. At the present stage, it is difficult to determine unequivocally whether this constitutes a significant drawback from the point of view of the piston-cylinder sleeve friction couple.

(a)

(b)

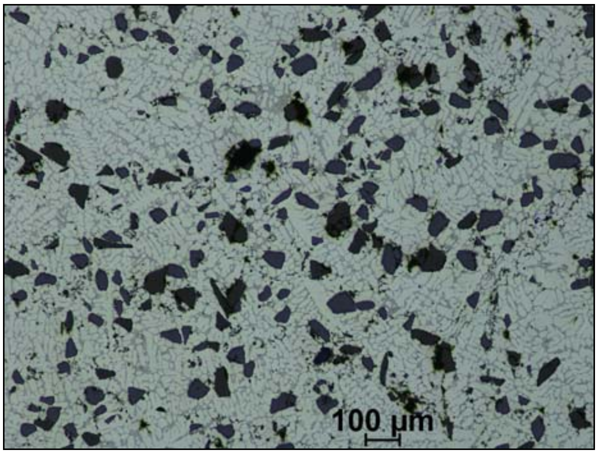

Fig. 2. a) Heterophase composite piston after mechanical working, b) microstructure of composite after permanent mould casting

Heads of composite pistons and mandrels made of spheroidal cast iron were used for testing the friction coefficient. Tests were carried out on the tester T-01M under dry friction conditions [10]. Resistance to wear of the samples tested was determined via gravimetric method by measuring the mass of the mandrels and discs directly before and after a tribological test (Tab. 1.). During the tests, the friction coefficient was measured in a continuous way. The obtained results are presented in the form of diagrams of changes of the friction coefficient and as a function of the friction distance (Fig. 3)

The composite material reinforced by means of SiC particles is characterised by a constant increase of the friction coefficient value throughout the distance (after 2,500 m, a value equal 0.45 was recorded). At the same time, the presence of glassy carbon in the heterophase composite (SiC+C) affects the stabilization of the friction coefficient value as a function of the friction distance and reduces the intensity of the wearing-in stage of the interacting surfaces. Both a decrease of the friction coefficient and the wear of the heterophase composites may be connected with the carbon particles' chipping effect and the deposition of its fragments on the surface of the interacting components of the friction couple, which forms a kind of a solid lubricating agent in the system.

4. Summary

On the basis of the performed tests, an advantageous interaction of glassy carbon particles in a couple consisting of a heterophase composite and a spheroidal cast iron has been corroborated. This should allow applying of this material to the composite piston - cylinder sleeve system in piston air-compressors. Further works will concern the selection of the matrix alloy composition with the purpose of reducing the phenomenon of particles chipping during machining. It seems that one of the possibilities is the application of a more plastic matrix and optimizing the fraction of reinforcing phases and their gradient distribution in the casting.

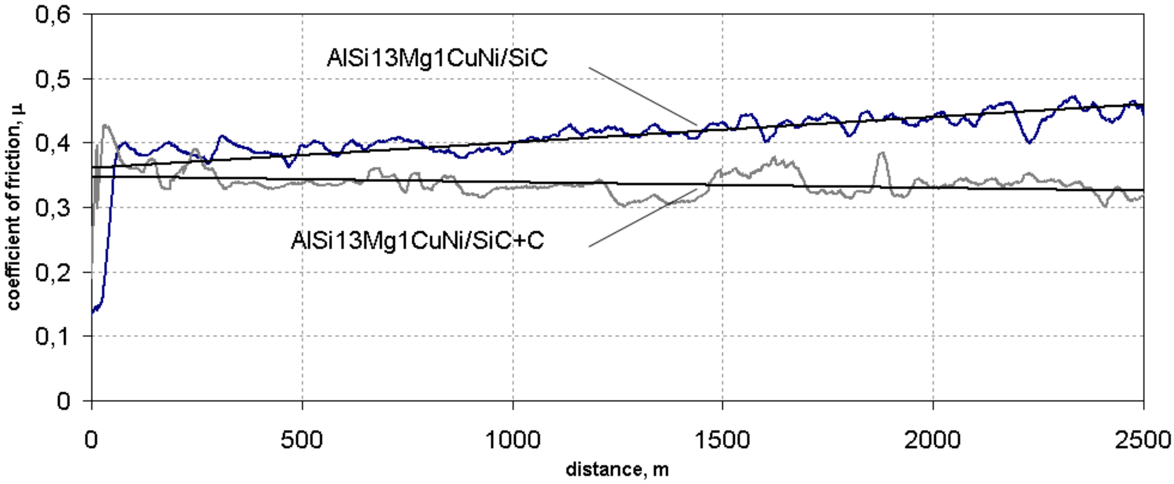

Fig. 3. Diagram of changes of the friction coefficient and as a function of the friction distance.

Table 1. Mass of the mandrels and discs directly before and after a tribological test.

	Discs mass [g]	Mandrels mass [g]
AlSi13Mg1CuNi – SiC		
Before friction	63,410	5,839
After friction	63,398	5,828
Mass decrement [g]	0,012	0,011
AlSi13Mg1CuNi – SiC+C		
Przed tarciem	71,633	5,476
Po tarciu	71,622	5,475
Mass decrement [g]	0,011	0,001

Acknowledgements

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