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CONTENT

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Application of hybrid composites based on ZA27 alloy in automotive industry

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Abstract *The field of application of ZA27 alloy is very wide due to favourable combination of physical, mechanical and tribological properties. In automotive industry, it is used for the production of engine cylinders and pistons, engine blocks, plain bearings, pumps, brakes, etc. Composites based on ZA27 alloy were developed with the aim of obtaining materials with better mechanical and tribological characteristics compared to the original matrix alloy. In this paper, special attention is given to metal matrix composites developed from ZA27 alloy with a high content of aluminium. Based on experimental research, the paper presents the tribological characteristics of hybrid composites based of ZA27 alloy and reinforced with silicon carbide and graphite particles. Experimental tribological tests were performed on a tribometer under different test conditions, by varying normal loads and sliding speeds. The obtained composites retain good mechanical properties at elevated temperatures and have better tribological properties compared to the base alloy. Application of the tested composites in the automotive industry is justified by their lower weight and high wear resistance. It directly affects the reduction of vehicle weight and gives positive economic and environmental effects.*

Keywords *ZA27, hybrid composites, automotive industry*

1. INTRODUCTION

The automotive industry is one of the largest consumers of various kinds of raw materials. The process of material selection during product development in this industry presents a hard endeavour of balancing between demands of corporation, market and society. Modern needs for lightweight, compact and impact-resistant vehicle designs are the key factors inducing the use of alternative materials to metals in automotive applications.

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Composite materials have been utilized in vehicle designs since 1945 (Stout Scarab vehicle's body structure with glass fibre reinforced plastic). Today, automotive producers are introducing new composite parts in their vehicles in order to meet the stringent emission norms, increase the fuel efficiency by reducing vehicle weight and increase the overall efficiency of vehicle manufacturing. Composites are commonly used to replace steel and other heavy materials because of their better structural and mechanical properties compared to other materials such as steel and aluminium.
Use of automotive composites in Europe has increased dramatically in recent years due to the presence of the key automotive manufacturers in Germany, UK, Poland, France, and Spain. It is anticipated that Europe

automotive composites market share will grow at a compound annual growth rate (CAGR) of 6.6% from 2019 to 2026, Fig. 1 [1].

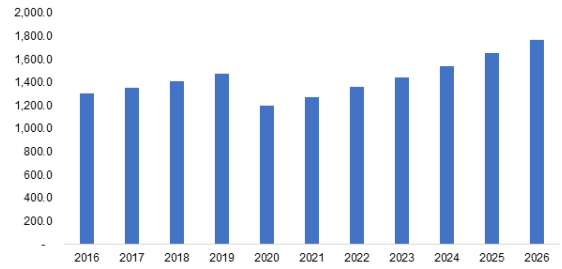

Fig. 1. Europe automotive composite market size, 2016 – 2026 (USD Million) [1]

Composite materials were majorly used for the exteriors of the vehicle (door frames, fenders, bumpers), but their application area has widened. Today, they are used in interiors, chassis, powertrain, under the hood parts and structural parts of the vehicle, Fig. 2, and provide distinct structural and weight advantages. In 2019, the biggest share in global automotive composite market (38.6%) belonged to exterior vehicle components, followed by interior components such as central console, carpets, steering wheels, cockpit modules, door panels, headliners and automotive seats [2].

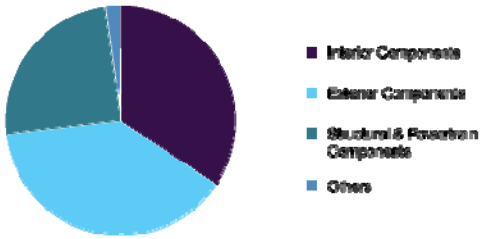

Fig. 2. Global automotive composite market share, by application, 2019 (%) [2]

Major types of composite materials which are used in automotive industry are: polymer matrix composites (PMC), metal matrix composites (MMC), ceramic matrix composite (CMC) and others (hybrid composites). In 2019, the biggest share of the automotive composite market (75.3%) had belonged to polymer matrix composites, followed by metal matrix composites and ceramic matrix composites. On the other hand, hybrid composites have gained preference in the recent years due to their lower cost in regard to single fibre composites.

Due to their low cost and easy fabrication method, polymer composites are most frequently used in inner door panels, roof modules, flaps, lids and dashboards. They are also known for improving the crash performance of vehicles.

Ground transportation (automotive and locomotive) segment dominates the metal matrix composites market, Fig. 3, with more than 50% share. Metal matrix composites for automotive applications are based on aluminium and its alloys. They are generally used for engine components (pistons, connecting rods, cylinder blocks, and valve train parts), brake components, fins, drive shafts and bearings.

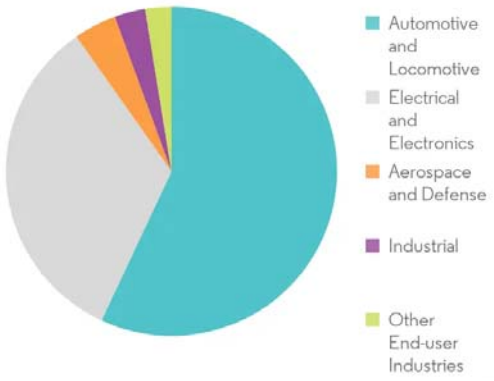

Fig. 3. Metal matrix composites market, Revenue (%), by end-user industry, global, 2020 [3]

Ceramic matrix composites have the high cost of production, but they are known for high strength, excellent corrosion and wear resistance and superior chemical and thermal resistance. Thus, their key applications in automotive industry are in brake disks, brake system components and clutches.

The largest end-use segment of hybrid composite materials market, the automotive and transportation segment, Fig. 4, is anticipated to register a CAGR of 13.9% from 2020 to 2027 [4]. Compared to automotive product made from traditional materials, hybrid composites offer higher strength, lower density, and higher impact resistance. Applications of hybrid composite materials in automotive industry include: seat backs, side and back door panels, boot liner, hat rack, spare tire lining,

windshield dashboard, business table, pillar cover panel, etc.

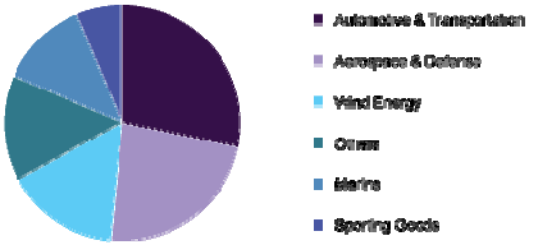

Fig. 4. Global hybrid composites market share, by end-use, 2019 [4]

2. APPLICATION OF ZA27 ALLOY AND COMPOSITES BASED ON ZA27 ALLOY

Zinc-aluminium alloys (ZA alloys) have higher concentrations of aluminium than traditional zinc alloys and have unparalleled bearing properties. Due to good mechanical characteristics (strength, hardness, toughness), ZA alloys are easy to machine and are especially suitable for the production of various types of bearings in the machine industry.

ZA27 alloy has the highest aluminium content of 27%. The basic alloying elements in ZA27 alloy are aluminium, copper and magnesium. The presence of aluminium has a favourable effect on strength and increases the fluidity of the alloy. The addition of small amounts of magnesium has a positive effect on corrosion resistance and on increasing the strength of ZA27 alloy. The presence of copper has a favourable effect on the hardness of the alloy and its tensile strength and creep resistance. ZA27 alloy is characterized by higher hardness and higher modulus of elasticity than aluminium alloy, which together with high strength provides high resistance of ZA27 alloy to abrasion and wear [5].

ZA27 alloy is also characterized by good technological properties, such as excellent castability, easy machining, good damping characteristics, the possibility of applying various surface protection procedures on castings, etc. It is very easy to machine, with minimal tool wear, resulting in items with clean and smooth surfaces.

Due to the favourable combination of physical, mechanical and technological properties, the field of application of ZA27 alloy is very wide.

ZA27 alloy has the lowest density of all ZA alloys, so its application can achieve a significant reduction in the total weight of structures (up to 60% if it replaces bronze products). In the automotive industry, grey cast iron components are increasingly being replaced by ZA27 alloy components, with a weight reduction of over 40%.

Castings made of ZA27 alloy are used in automobile engines and drive mechanisms, for the manufacture of machine tools, presses, pumps, household appliances, agricultural machinery, in the chemical, textile and construction industries, on railways, in refineries, in electric power plants, thermal power plants and foundries. Due to its good electrical and thermal conductivity, it is used in various cooling systems.

Many cast aluminium alloys are being replaced by ZA27 alloy which, in addition to high strength, also has high resistance to wear and atmospheric corrosion. This enabled the commercial application of this alloy as a significant tribo-material, primarily for the manufacture of plain bearings and sleeves.

ZA27 alloy is non-magnetic, which makes it suitable for use in electronic devices. Due to good vibration absorption, it is widely used for the manufacture of various housings.

ZA27 alloy is also acceptable from the ecological point of view, because, according to EU legislation, it is not classified as a hazardous material, which is important for its application in automotive industry.

Relatively low melting temperature of ZA27 alloys requires less energy for melting and casting, so the production costs are lower. However, the mechanical properties of the alloy deteriorate at elevated temperatures, i.e. its hardness and strength decrease. One way to reduce the deterioration of the mechanical properties of ZA27 alloy at elevated temperatures is to make composites based on this alloy.

A composite material is a compound of two or more materials with different characteristics, which has different properties with respect to the constituent components. The production of composite materials has been in continuous expansion since the 1970s. It is expected that this production will reach its maximum in the middle of the 21st century. Composites are used in the aerospace, automotive and electronic industries, medicine and construction [6].

Graphite is nontoxic and acts as a lubricant, so it is used to make composites with a ZA27 base, from which bearings, pistons of automobile and other engines and cylinder liners are produced, Fig. 5.

Fig. 5. Connecting rod and engine piston

Cheap and reliable housings of mechanisms for moving seats in vehicles, are shown in Fig. 6.

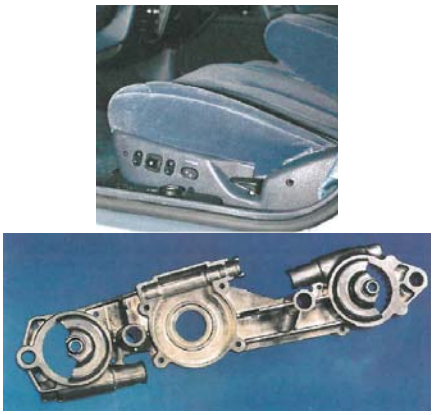

Fig. 6. Mechanism for moving the vehicle seats

The ZA27 alloy is also used for manufacture of plain bearings, gears, plain slats, worm wheels and similar parts, for which good tribological properties are required. The structural and mechanical characteristics of ZA27 alloy, which are extremely important for its application, can be influenced by heat treatment. Thus, the heat-treated ZA27 alloy can be used to make elements such as worm gears, gears, etc, Fig. 7.

Fig. 7. Manufacture of gears

High wear resistance is a consequence of the high hardness of ZA27 alloy and its natural lubricity. Thanks to this, ZA27 alloy plain bearings are increasingly used as a direct replacement for bronze bearings, especially when it comes to larger bearings, Fig. 8.

Fig. 8. Bearings for working machines

The best bearing characteristics of ZA27 alloy are found when used in conditions of high loads and low sliding speeds, with lubrication. The bearings also have improved wear characteristics, because deformation of the graphite particles results in the formation of a continuous graphite film, which provides self-lubrication of the component, allowing for improved component longevity.

3. PROPERTIES OF HYBRID COMPOSITES BASED ON ZA27 ALLOY OBTAINED BY EXPERIMENT

Due to its wide temperature range of solidification, ZA27 alloy is very suitable as a metal base for obtaining composites by the compocasting procedure.

The composting procedure is one of the most promising procedures for obtaining composites. This procedure is increasingly used in the commercial production of composite materials, given the savings in energy and material, as well as the relatively low temperature at which the process takes place [7].

The paper presents the results of testing the tribological behaviour of ZA27 alloy as well as the composite reinforced with SiC particles (ZA27+5%SiC) and the hybrid composite reinforced with SiC and Gr particles

(ZA27+5%SiC+3%Gr). Both composites are based on the ZA27 alloy.

Tribological tests were performed using a block-on-disc tribometer.

The dependences of the wear scar width on the sliding speed and the normal load for ZA27 alloy and the two observed composite materials are shown in Figs. 9 to 11, respectively.

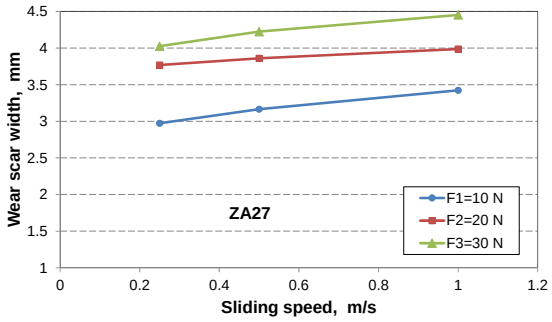

Fig. 9. Dependence of wear scar width on sliding speed for ZA27 alloy

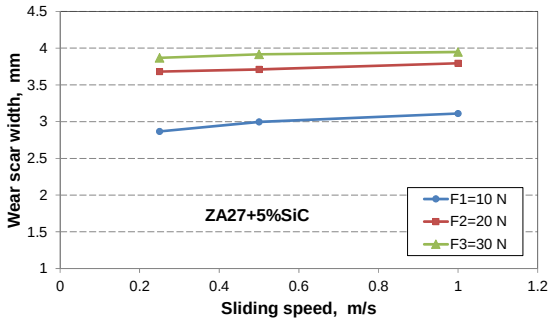

Fig. 10. Dependence of wear scar width on sliding speed for ZA27+5%SiC composite

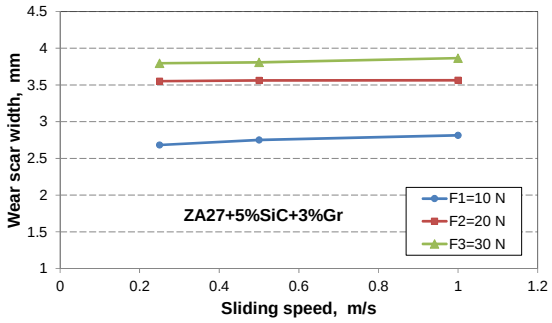

Fig. 11. Dependence of wear scar width on sliding speed for ZA27+5%SiC+3%Gr hybrid composite

The values of the wear scar widths given in the figures represent the mean values after three tests were performed under the same operating conditions (dry sliding, normal loads of 10 N, 20 N and 30 N, sliding speeds of 0.25 m/s, 0,5 m/s and 1 m/s). It can be observed that the wear scar width increases with the increase in sliding speed and applied normal loads. This applies to all tested materials. Hybrid composite ZA27+5%SiC+3%Gr has the smallest values of wear scar widths, which means that it has the best tribological characteristics for all testing conditions.

Wear rates for all materials were obtained by calculation based on the known geometry of the contact pair and on the volumes of the worn material. Analytical and graphical dependences between the wear rate and the adopted parameters are presented in Figs. 12 to 14 [8].

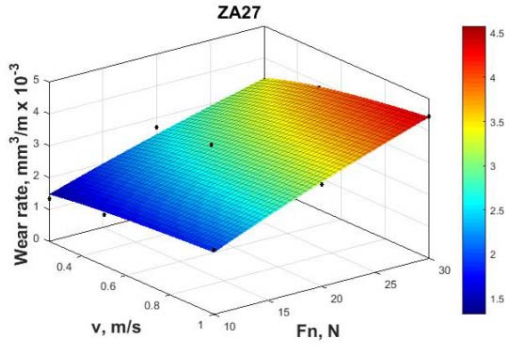

Fig. 12. The wear rate surface for ZA27 alloy

The wear rates of the tested composites are smaller than the wear rates of the ZA27 alloy for all the applied sliding speeds and normal loads.

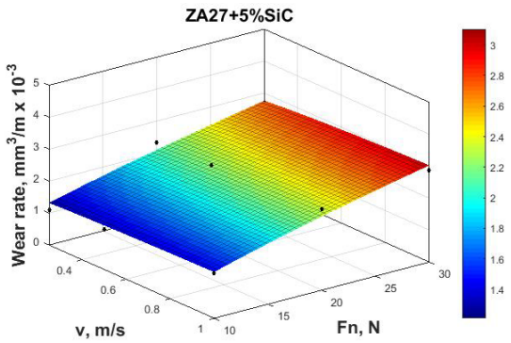

Fig. 13. The wear rate surface for ZA27+5SiC composite

Values of the wear rates of all tested materials increase with the increase of the normal load

and also increase with the increase in the sliding speed.

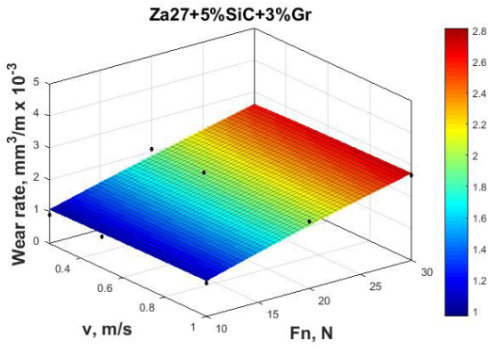

Fig. 14. The wear rate surface for ZA27+5SiC+3Gr hybrid composite

4. CONCLUSIONS

Modern automotive producers must face the challenges imposed by strict emission regulations and better fuel economy demands. Part of the solution to these problems is found in application of composite materials in vehicle design. Their properties like high-strength, wear-resistance and self-lubrication can be customized in order to obtain significant weight reductions and improved fuel efficiency of the vehicles.

Hybrid composites based on ZA27 alloy, which contain SiC particles and graphite, are materials with significant tribological potential for application in the automotive industry. Experimental research have shown that these composites are characterized with high hardness, high wear resistance and good overall tribological properties. Projections from market reports forecast the increase in use of this lightweight and high-strength alternative for traditional fiberglass and metal applications in the automotive industry.

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