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Tribological properties of silver matrix composites

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Abstract:
Silver, silver alloys, as well as matrix based composites have been well known and applied in the electrotechnical and electronics industry for several decades. For many applications in electrotechnology, including electric contacts and brushes, unreinforced sliver alloys do not meet the requirements concerning mainly durability and wear resistance, first of all to tribological and electroerosive wear. These wear processes may be prevented by introducing to silver reinforcement particles. It can be stated, comparing recorded friction coefficient values of all investigated materials, that in the dry sliding conditions the ceramic particles introduction into matrix has its effect on the friction coefficient value lowering. If metallic particles are used as reinforcement, and in the investigated composites iron particles were used, the friction coefficient increases its value comparing to the matrix.

Key words Tribological properties, silver matrix composites, wear.

1. Introduction

Constructional elements made of silver in technical applications might be exposed to the destructive tribological influences. In the case of elements such as electric contacts or joints apart from influences resulting from the passage of current, that is the contact temperature increasing or sparking, their tribological wear should be taken into account as well. It results from reciprocal movement of cooperating elements or from the presence of the vibration. Such coupling effects and reciprocal tribological influences should be limited because of silver and some of its alloys susceptibility to the adhesive coupling forming already in 150 °C.It might be achieved through the composite materials reinforced with ceramic particles or ceramic short fibre application [1].

The influence of the reinforcement in the form of the particles on the metal matrix composites tribological properties is known on the grounds of the literature and a number of own authors investigations. Apart from hardness of the cooperating surfaces increasing the reinforcing particles presence it leads to the increase of cooperating elements resistance to the abrasive wear. Ceramic particles and especially Al_2O_3 or SiC hard ceramic and glass carbon particles may also efficiently counteract adhesive coupling forming. It consist from one side in the limitation of the pure matrix metal contact surface with the friction partner and from the other in the adhesive coupling shearing (interruption) formed within the matrix [2].

Assuming such reinforcing particles interaction in silver and its alloys matrix composites the investigations were taken up aimed at these materials tribological properties evaluation. It was moreover assumed that they should be conducted in dry sliding conditions as for the reason of their utilization in the electronics and electrotechnical industry the lack of lubrication should be assumed [3.4].

2. The characteristic of tested materials

The composites used in the tests were reinforced with SiC, Al_2O_3, Cs (glass carbon), and Fe. All composites were produced with the use of liquid-phase method employing liquid metal mixing technology with the simultaneous introducing appropriately prepared particles or composite master alloy into it. Produced suspension was mixed with the graphite mixer and cast into the graphite form [5,6]. Obtained in such way composite may be re-melted and casted or subjected to plastic working. Phase composition of the five different composite materials prepared for the tests is presented in the Tab. 1. Obtained composites in the form of 50mm diameter ingots were subjected to the extrusion with the KOBO press in Kruel firm getting 10mm diameter wires.

Table 1.
Composites subjected to tribological tests determining and phase composition

Sample designation	Disk material	
	Matrix	Reinforcement
Ag - SiC	AgAlSi Alloy	Sic 20 μm
Ag - Fe	Ag	Fe 60 μm
Ag - Cs	AgAlMg Alloy	Glass carbon 80μm
Ag – Al_2O_3	AgAlMg Alloy	Al_2O_3 20 μm
Ag	AgAlMg Alloy	-
	Pin material	
	Matrix	Reinforcement
Ag - SiC	AgAlSi Alloy	SiC 20 μm
Ag - Fe	Ag	Fe 60 μm
Ag - Cs	AgAlMg Alloy	Glass carbon 80μm
Ag – Al_2O_3	AgAlMg Alloy	Al_2O_3 20 μm
Ag	AgAlMg Alloy	

In the case of investigated composites reinforced with ceramic and metallic particles plastic working with the use of extrusion methods did not present any problems. The only negative effect was bad wires surface quality which results both from the extrusion process specificity and from ceramic particles presence in the silver matrix. This problem was solved through the machining application as an element of the samples allotted for the tests preparing.

Investigated composite materials after the extrusion process were evaluated with regard to a structure and their hardness was tested as well. The hardness tests were conducted with the use of the Brinell apparatus. 2,5 mm diameter ball and a 180N load was applied. The obtained hardness tests results are presented in the form of a graph in the Fig. 1.

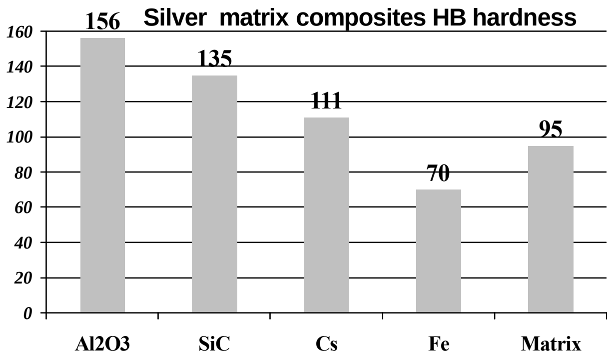

Fig. 1. The results of silver matrix composites hardness testing with the use of Brinell method.

Composite structure tests made with the use of light microscopy and SEM allowed to evaluate reinforcing particles distribution. Microscopic examination allowed to determine friction tracks so that the surface participation for each of the tested materials was comparable. The selected composite structures used in tribological tests are presented in the Figures 2 and 3.

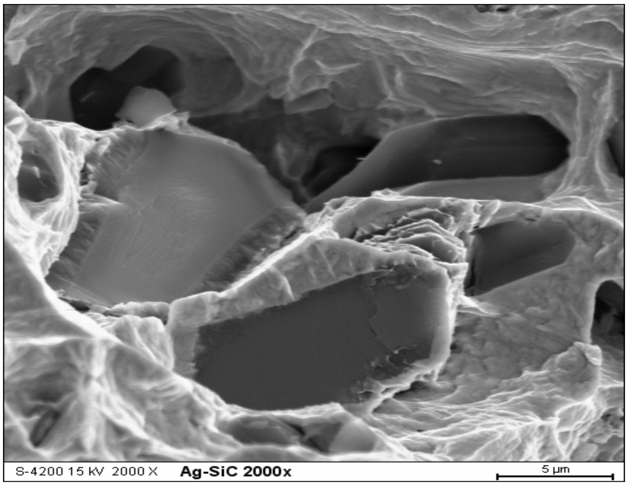

Fig. 2 Silver matrix composite reinforced with SiC 20μm particles.

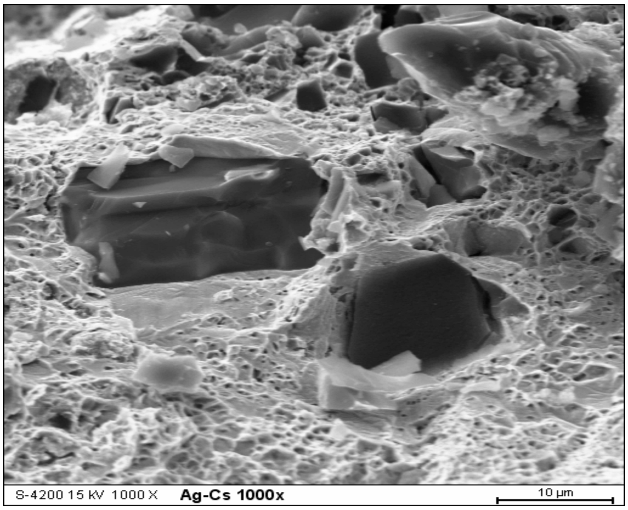

Fig. 3. Silver matrix composite reinforced with glass carbon 80μm particles.

3. Tribological tests

The friction coefficient value and abrasive wear were tested with the use of pin-on-disc method (T-01). A material fragment 50 mm diameter and 4 mm thickness left after the ingot extrusion was used as a disk and composite wires obtained after the extrusion were used as a pin. The samples were turned from the extruded 10 mm diameter wires. The characteristic parameters applied in tribological tests completion are presented in the Tab. 2. Tribological tests were conducted in the dry sliding conditions with the T-01 pin-on-disc tester. The schema of the measuring stand is presented in the Figure 4.

Table 2.
The parameters applied during tribological tests.

Pin diameter	3 mm
Friction velocity	0,5 m/s
Unite pressure	2,5 MPa
Friction distance	3500
Association sort	Dry sliding
Friction radius	12 mm

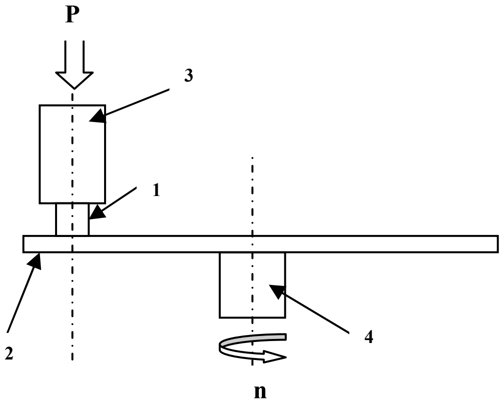

Fig. 4. Schema of T-01 tester schema: 1-pin P = 2,5 MPa, 2-composite disk rotating with n = 0,5m/s velocity, 3 clamp, 4-spindle.

During the test friction coefficient was measured in a continuous way. Composites tribological characteristics, that is friction coefficient measured in a 3500m distance, were compiled in a graph and presented in a figure 5.

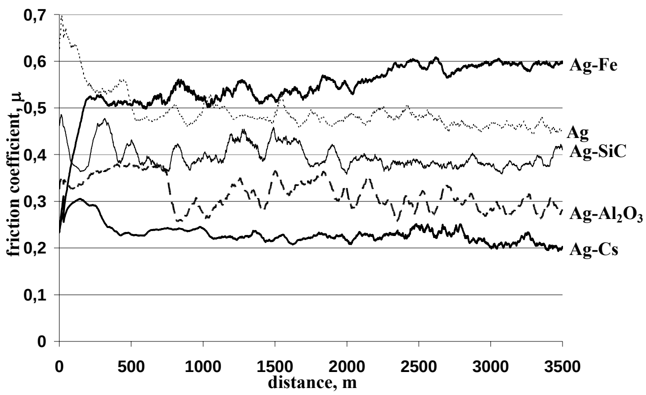

Fig. 5. The course of friction coefficient value changes in a distance function for the investigated tribological associations.

It is favourable from the sliding properties point of view to obtain the lowest friction coefficient value possible. Amongst investigated associations composite reinforced with the glass carbon particles is characterized by the lowest friction coefficient. In this case its value fluctuates around $\mu = 0,22$. The highest friction coefficient value and therefore the least favourably sliding properties characterize Ag-Fe composite. The friction coefficient reaches $\mu = 0,6$ value. Slightly lower friction coefficient value $\mu = 0,47$ was recorded for the unreinforced matrix alloy. Such a result may indicate numerous adhesive coupling accompanying the friction process of these materials. The lack of reinforcement in the form of ceramic particles in the matrix and in the case of Fe particles reinforcement, the presence of the material with the similar to silver tendencies to the adhesive coupling forming, trigger the effect of friction coefficient value increase.

It is confirmed by the results of the wear level measurement and microscopic pictures of the wear track (Fig. 6-8). Amongst composites reinforced with ceramic particles, composite reinforced with the silicon carbide particles is characterized by the highest friction coefficient $\mu = 0,4$ in this case. Almost 0,1 lower friction coefficient was recorded for the composite reinforced with alumina particles, friction coefficient value equaled $\mu = 0,3$.

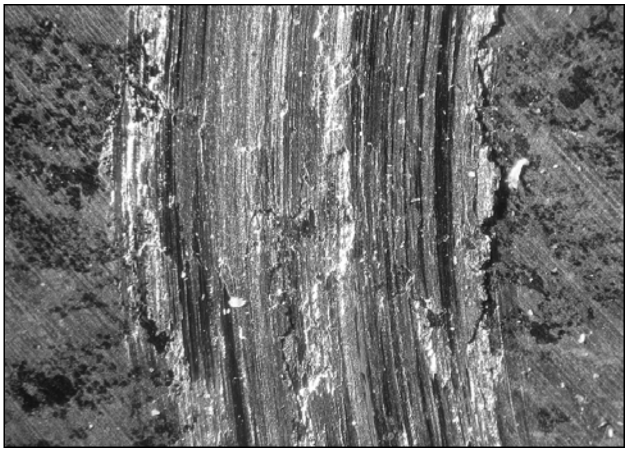

Fig. 6. Ag-Fe composite wear track with visible numerous adhesive coupling tracks, mag. 50x.

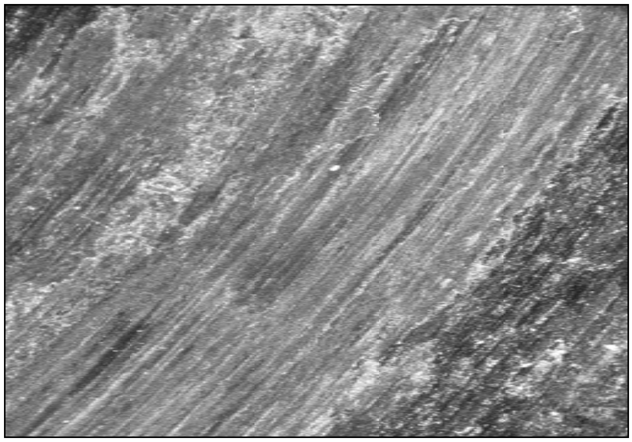

Fig. 7. Ag-SiC composite wear track with the visible ridging as a abrasion result, mag. 50x

In both cases (SiC and Al_2O_3) reinforcing particles size was the same and equaled 20 μm. The lowest friction coefficient amongst investigated composites was recorded for the composite reinforced with glass carbon particles 80mm size μ = 0,22 value in this case. Such a law friction coefficient value in the case of reinforcement in the form of glass carbon application should be connected with the character of wear of carbon itself. Glass carbon being worn in the friction process creates the layer of solid lubricating agent (Fig. 8) staying in the cooperating system as the third substance, lowering thereby friction coefficient and wear value.

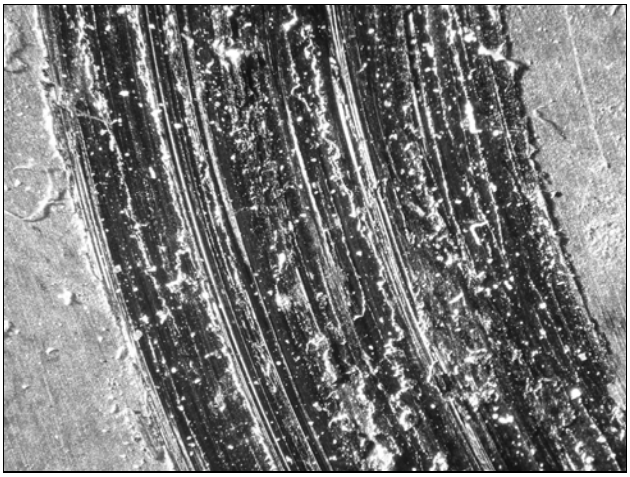

Fig. 8. Ag-glass carbon composite wear track with the visible ridging as a abrasion result, mag. 50x.

Silver matrix composite material wear investigations consisted in the determining of the mass decrement risen during presented above T-01 tester tests. The system wear was treated as the total tribological system mass decrement that is the total sum of the disk and cooperating with it pin mass decrements. The results are presented in the Figure 9.

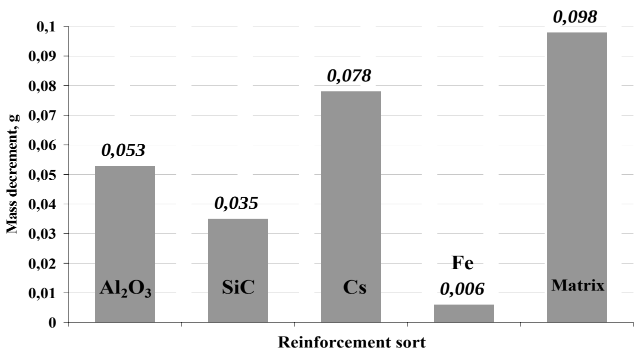

Fig. 9. Silver matrix composite materials wear expressed by tribological system mass decrement.

The little value of the Ag-Fe (0,006g) composite mass decrement compared to the recorded friction coefficient (μ = 0,6) may prove adhesive character of this system wear process. The comparison of mass decrements, friction coefficient value and the image of the wear track confirm abrasive wear mechanism acting there.

4. Summary

It can be stated, comparing recorded friction coefficient values of all investigated materials, that in the dry sliding conditions the ceramic particles introduction into matrix has its effect on the friction coefficient value lowering. If metallic particles are used as reinforcement, and in the investigated composites iron particles were used, the friction coefficient increases its value comparing to the matrix.

Amongst applied ceramic materials glass carbon application influences the most friction coefficient value lowering.

Investigated materials are characterized by even wear and this allows to think that they will be able to work in the dry sliding conditions. However making investigations for different sliver matrix composite associations aimed at least wear degree association determining is essential.

Acknowledgments

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