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J. WIECZOREK*,#, B. OLEKSIAK**, J. ŁABAJ**, B. WĘCKI**, M. MAŃKA**

SILVER MATRIX COMPOSITES - STRUCTURE AND PROPERTIES

Phase compositions of composite materials determine their performance as well as physical and mechanical properties. Depending on the type of applied matrix and the kind, amount and morphology of the matrix reinforcement, it is possible to shape the material properties so that they meet specific operational requirements. In the paper, results of investigations on silver alloy matrix composites reinforced with ceramic particles are presented. The investigations enabled evaluation of hardness, tribological and mechanical properties as well as the structure of produced materials. The matrix of composite material was an alloy of silver and aluminium, magnesium and silicon. As the reinforcing phase, 20–60 µm ceramic particles (SiC, SiO_2, Al_2O_3 and Cs) were applied. The volume fraction of the reinforcing phase in the composites was 10%. The composites were produced using the liquid phase (casting) technology, followed by plastic work (the KOBO method). The mechanical and tribological properties were analysed for plastic work-subjected composites. The mechanical properties were assessed based on a static tensile and hardness tests. The tribological properties were investigated under dry sliding conditions. The analysis of results led to determination of effects of the composite production technology on their performance. Moreover, a relationship between the type of reinforcing phase and the mechanical and tribological properties was established.

Keywords: silver matrix composites, tribological properties, mechanical properties

1. Introduction

Regarding technical applications, structural components made of silver and its alloys are exposed to destructive tribological effects. In the case of such elements as electrical contacts or connections, their tribological wear should be considered in addition to effects resulting from electric current flow, i.e. contact temperature rise or sparking [1,2]. This is related to interactive movement of the components due to e.g. vibrations.[3-6] Under such operating conditions, the main reason of tribological wear is the tendency of silver and its certain alloys to develop adhesive bonds as early as at 150°C. [7-9] Such bonds, being a base for creation of some of composites [10], contribute in specimen's surface injuring and – with increase in temperature – increasingly become a leading wear mechanism. Therefore, the effects of these bonds as well as of tribological interactions of the component surfaces must be limited. They are managed through application of composite materials reinforced with ceramic particles or short fibres, such as: Ag-SnO_2, Ag-Al_2O_3 [1, 3, 11-14].

Impact of the particle reinforcement on the tribological properties of metal matrix composites has been known based on, among others, a number of the authors' individual studies[2, 11-12]. Presence of reinforcing particles in the metal matrix, in addition to increased hardness of the interacting surfaces, primarily results in improved resistance of the interacting components to abrasive wear. Ceramic particles, especially hard ceramics (Al_2O_3 or SiC), and glassy carbon particles can effectively prevent formation of adhesive bonds through reducing the contact surface of matrix pure metal and the friction partner as well as cutting (breaking) the forming adhesive bonds within the matrix [6-9, 11].

2. Characteristics of the investigated material

The investigated composites were reinforced with SiC, Al_2O_3, and Cs (glassy carbon) particles as well as with their mixture. The composites were produced by means of the liquid phase method, applying the technology of liquid metal stirring with simultaneous implementation of adequately prepared particles [15-17]. The metal was melted in an induction furnace with a graphite crucible, which ensured that the silver alloy was protected from oxygen saturation. The resulting composite suspension was stirred using a graphite stirrer and transferred to a graphite mould. This type of material can be remelted and cast or subjected to plastic work [9, 16-19]. For investigation purposes, five various composite materials were prepared. Their phase compositions are presented in Table 1.

The produced composites (ingots of 50 mm in diameter and 50 mm in height) were subjected to extrusion by means of the KOBO method to produce 10 mm rods. In the case of investigated composites reinforced with ceramic particles, the plastic work (extrusion) was successfully completed. Its only disadvantage was a poor quality of the rod surfaces,

* SILESIAN UNIVERSITY OF TECHNOLOGY, FACULTY OF MATERIAL SCIENCE AND METALLURGY, INSTITUTE OF MATERIALS SCIENCE, 40-019 KATOWICE, 8 KRASIŃSKIEGO STR.POLAND

** SILESIAN UNIVERSITY OF TECHNOLOGY, FACULTY OF MATERIAL SCIENCE AND METALLURGY, INSTITUT OF METALS TECHNOLGY, 40-019 KATOWICE, 8 KRASIŃSKIEGO STR.POLAND

Corresponding author: jakub.wieczorek@polsl.pl

which results from the nature of the extrusion process and the presence of ceramic particles in the silver alloy matrix.

TABLE 1

Labels and the phase compositions of composites subjected investigations

Label	Matrix	Particles		
		Type	Diameter, mm	Surfacefraction, %
Ag - SiC	AgAlSi	SiC	20	10
Ag - Cs	AgAlMg	Glassy carbon	60	10
Ag - Al_2O_3	AgAlMg	Al_2O_3	20	10
Ag – SiO_2	AgAlMg	SiO_2	20	10
Ag(AlMg)	AgAlMg	-	-	-

Following extrusion, the investigated composites were assessed for their structure, hardness and mechanical properties. The hardness test was performed by means of a Brinell tester, using a 2.5 mm (diameter) ball and 180 N load. The hardness test results are presented in Figure 1

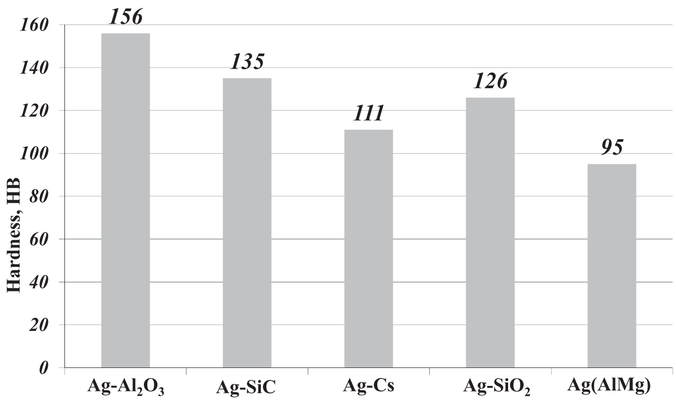

Fig. 1. Results of the Brinell hardness test for silver matrix composites

Tensile strength was tested for 10 mm (diameter) rods following extrusion. For the investigation purposes, an INSTRON 4468 testing system with a 50 kN load cell was used. The test rate was 5 mm/min (standard for composite materials [20]) for specimens of a 100 mm gauge length. The investigations were performed on immediate post-extrusion composites and the material subjected to 2-hour annealing at 600°C. Typical stress-strain curves for the composites are presented in Figure 2. Mean tensile strength and strain values are shown in Table 2. The presented results refer to the material after annealing at 600°C.

TABLE 2

Tensile strength and strain values

	Ag(AlMg)	Ag-Cs	Ag-Al_2O_3	Ag-SiC
Rm, MPa	73	105	100	32
A50, %	3.8	3.9	3.3	3.9

The composite tensile tests showed that immediate post-extrusion composites demonstrated high brittleness and, therefore, their strength could not be adequately assessed. The tensile test was only possible after heat treatment (2-hour annealing at 600°C).

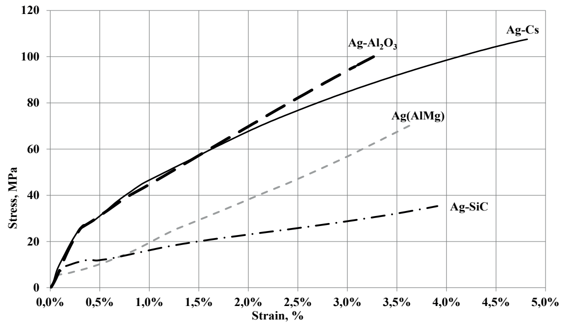

Fig. 2. Stress-strain curves for silver matrix composites following extrusion and annealing at 600°C/2h

Composite structure investigations with the use of light microscopy and SEM enabled evaluation of the reinforcing particle distribution. In addition to the quality assessment of the bond between the matrix and the reinforcement, the investigations allowed for determination of the sliding distance so as the surface fraction of the ceramic particles was comparable in each composite. Areas of the 10–15% surface fraction were chosen. Selected structures of composites used in the tribological investigations are presented in Figures 3, 4 and 5.

a) b)

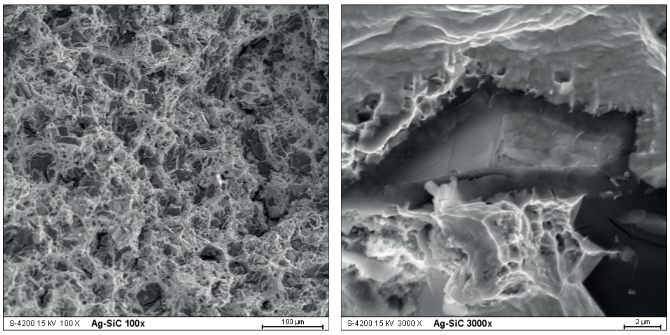

Fig. 3. Ag-matrix composite reinforced with 20 mm SiC particles: a) distribution of the particles in the matrix, b) fracture observed following the tensile test

a) b)

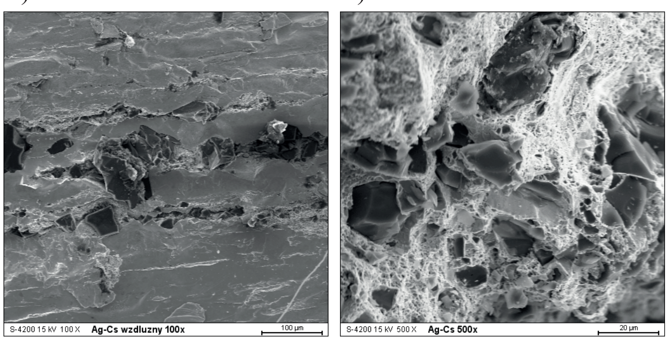

Fig. 4. Ag-matrix composite reinforced with 60 mm glassy carbon particles: a) distribution of the particles in the matrix, b) fracture observed following the tensile test

a) b)

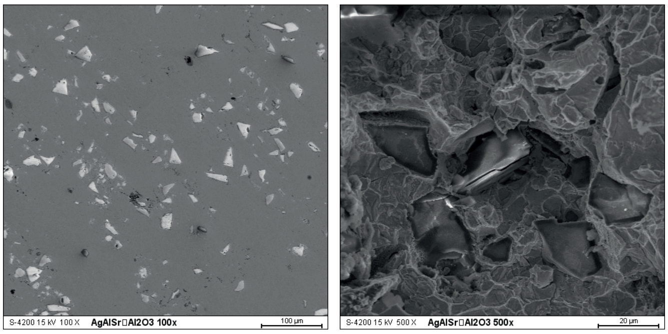

Fig. 5. Ag-matrix composite reinforced with 20 mm Al_2O_3 particles: a)distribution of the particles in the matrix, b) fracture observed following the tensile test

3. Tribological investigations

For the composites, the value of friction coefficient and the level of abrasive wear were determined using the pin-on-disk method. The tribological tests were performed under dry sliding conditions for the distance of 3500 m. A schematic diagram of the measurement stand is presented in Figure 6.

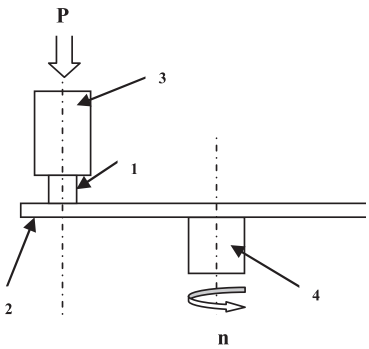

Fig. 6. Schematic diagram of the measurement system T-01 used for the investigations: 1 - pin P = 2.5 MPa, 2 - disc rotating at n = 0.5 m/s, 3 – clamping collet, 4 - spindle

The disk (10 mm thick) and the pin (3 mm in diameter) were produced using a composite rod obtained by means of extrusion. In Table 3, characteristic parameters applied for the tribological investigations are presented.

TABLE 3

Parameters used during the tribological investigations

Pin diameter	3 mm
Sliding rate	0.5 m/s
Unit load	2.5 MPa
Sliding distance	3500 m
Type of pairing	Dry sliding

The friction coefficient values for the distance of 3500 m are presented in Figure 7. Among the investigated pairings, the smallest friction coefficient is observed for the composite reinforced with glassy carbon particles: approximately μ = 0.22. The highest friction coefficient and, thus, the least beneficial sliding properties, are observed for the Ag matrix: the friction coefficient amounts up to μ = 0.5.

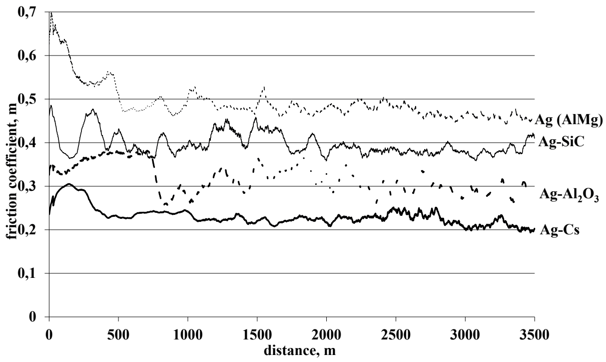

Fig. 7. Friction coefficient changes vs. the sliding distance for the investigated tribological pairings

A slightly smaller friction coefficient, μ = 0.47, was observed for the non-reinforced matrix alloy. This result may suggest that there are many adhesive bonds during the friction of these materials. Absence of matrix reinforcement with ceramic particles result in increased friction coefficient values, which has been confirmed by results of wear level measurements using the profilometric method and by microscopic images of the wear trace (Figures 8 and 10).

a) b)

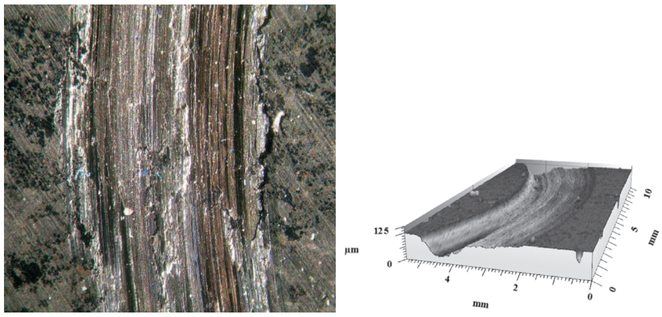

Fig. 8. Wear trace of the $Ag\text{-}Al_2O_3$ composite with abrasion-related ploughing (zoom: 50x)

a) b)

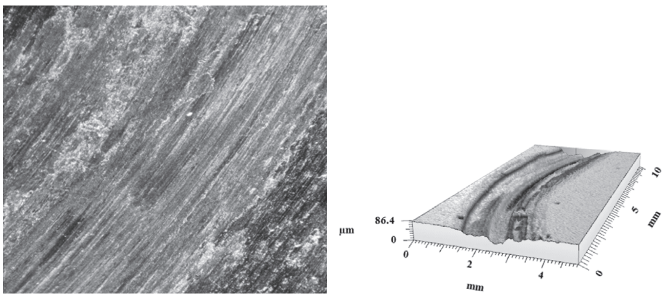

Fig. 9. Wear trace of the Ag-SiC composite with abrasion-related ploughing (zoom: 50x)

Among composites reinforced with ceramic particles, the highest friction coefficient under dry sliding conditions is observed for the composite reinforced with silicon carbide particles. In this case, the friction coefficient is μ = 0.4. A nearly 0.1 lower friction coefficient was recorded for the composite reinforced with aluminium oxide particles: μ = 0.3. In both cases, the size of reinforcing particles (SiC and Al_2O_3) was 20 mm. The smallest friction coefficient among the investigated composites was observed for the material reinforced with glassy carbon particles sized 80 mm: μ = 0.22. Such a small value should be associated with the nature of wear of carbon itself. During friction, glassy carbon (while wearing) produces a layer of permanent lubricant (Fig. 10) and remains in the system as a third component, markedly reducing the wear level and the friction coefficient value.

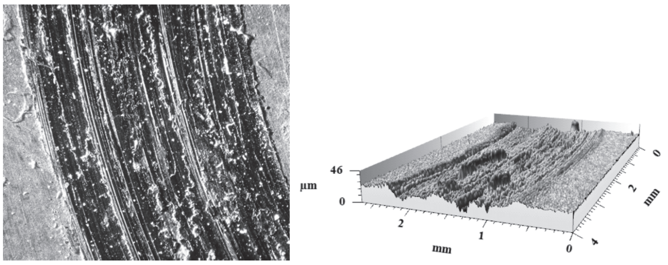

Fig. 10. Wear trace of the Ag-Cs composite with abrasion-related ploughing (zoom: 50x)

The wear levels for silver matrix composites were determined as the mass loss during dry sliding. The wear level for the system was the total loss of the tribological pairing mass, i.e. the sum of the block and interacting pin mass losses (Fig. 11).

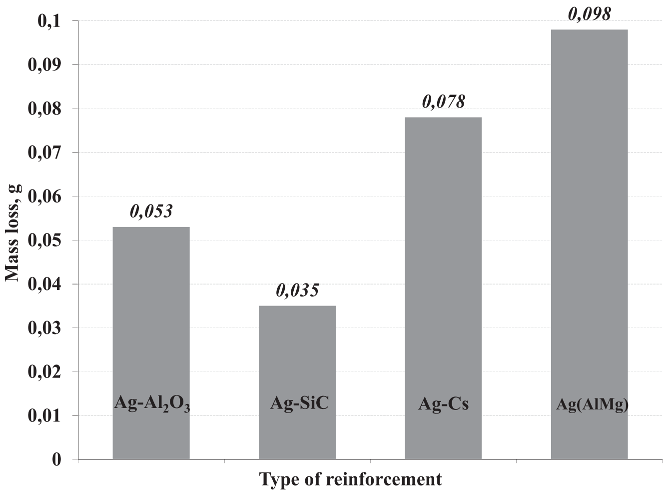

Fig. 11. Wear levels for silver matrix composites expressed as losses of the tribological system mass

A comparison of the mass losses and the friction coefficient values as well as the wear trace images for the composites reinforced with silicon carbide or aluminium oxide particles confirm the abrasive mechanism of wear.

4. Summary

In terms of sliding properties, it is beneficial to obtain the smallest possible friction coefficient value and the lowest wear level for the interacting components. While comparing the observed friction coefficients of all investigated materials, it can be observed that under dry sliding conditions, reinforcement of the silver matrix with ceramic particles results in a smaller friction coefficient.

The investigated materials demonstrate uniform wear levels, which allows assuming they can operate under dry sliding conditions. However, it is necessary to carry out investigations for various silver matrix composite pairings to determine those of the lowest wear levels.

5. Conclusions

1. Application of ceramic particles as the reinforcing material in silver matrix composites results in smaller friction coefficient values and lower levels of the friction component wear.
2. When glassy carbon particles are used as the reinforcement for the silver matrix, they most effectively reduce the friction coefficient value and, compared with silicon carbide and aluminium oxide particles, the friction pairing wear level.
3. Reinforcement of the silver matrix with ceramic particles results in a higher hardness level and slightly improved mechanical properties providing previous heat treatment of the composites.

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