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RESEARCH

Wear-resistance of Aluminum Matrix Microcomposite Materials

Abstract: *A procedure is developed for the study of wear of aluminum alloys AlSi7 obtained by casting, reinforced by TiC microparticles, before and after heat treatment. Tribological study is realized under conditions of friction on counterbody with fixed abrasive. Experimental results were obtained for mass wear, wear rate, wear intensity and wear-resistance of the alloys with different wt% of microparticles.*

Keywords: *tribology, composite aluminum alloys, microparticles, wear, wear-resistance.*

1. INTRODUCTION

Subject of tribotechnologies is the production and control of surface layers and coatings with physico-chemical and mechano-geometrical characteristics, which provide optimal regime of friction and wear in different exploitation conditions. Composite materials with Al matrix are relatively new materials, the minimum specific weight and excellent mechanical and tribologcal properties of which make them unique for contact joints, especially for applications in aircraft and automotive industry. The modern stage of advance of these materials is characterized by development of new kinds reinforcing and matrix components. A lot of studies are related to the influence of nature, size and *wt%* contents of the disperse particles of silicon carbide, titanium carbide, tungsten carbide, titanium nitride, etc. [1],[2],[4],[5],[6].

A research team at the Technical University of Sofia works systematically on the development of technologies for obtaining micro- and nano-composite aluminum base materials, and on the study of their properties [3].

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The purpose of the present research is development of the procedure and comparative study of wear and wear-resistance of aluminum alloys (*AlSi7*) with microparticles of titanium carbide (*TiC)* of the size 1.25 to 2.5 μm, before and after heat treatment. The reinforcement of the aluminum alloy is realized by molding with different contents of microparticles in percentage of casting weight.

2. EXPERIMENTAL STUDY, RESULTS AND DISCUSSION

Wear and wear-resistance are studied for two groups of specimens – as-cast and heat treated, reinforced with different, but one and the same for both groups, contents of microparticles. The study is carried out under conditions of dry friction against counterbody with fixed abrasive, keeping equal conditions of the experiment.

Table 1 shows some of the data and characteristics for both kinds of specimens.

Table 1: Characteristics of the composite materials

№	Code	wt% TiC	Technological data
1	Л-0	0 %	as-cast
2	Л-0,5	0,5 %	as-cast
3	Л-2	2 %	as-cast
4	Л-5	5 %	as-cast
5	Л-10	10 %	as-cast
6	Л-15	15 %	as-cast
7	ТО-0	0 %	heat treated
8	ТО-0,5	0,5 %	heat treated
9	ТО-2	2 %	heat treated
10	ТО-5	5 %	heat treated
11	ТО-10	10 %	heat treated
12	ТО-15	15 %	heat treated

2.1 Procedure and device for experimental study of abrasive wear

The study of wear is realized by means of pin-on-disk device in the Laboratory of Tribology at the Technical University of Sofia, Faculty of Machine Technologies. The procedure meets the requirements of the acting standards, especially the Bulgarian State Standard БДС 14289-77 (matching ISO) *Method for testing of abrasive wear at friction on fixed abrasive particles*.

The functional scheme of the device is given in Figure 1.

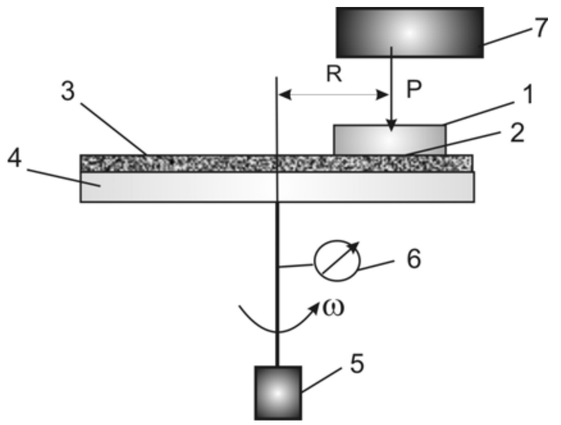

Figure 1. Functional drawing of the device for testing of abrasive wear

The specimen 1 (body) is of the form of parallelepiped with dimensions of the basis 10 x10 mm and height 25 mm. The counterbody 3 is abrasive surface, which is modeled by impregnated corundum with given characteristics – hardness of 60% higher of the microhardness of the surface layer of the tested material and given average size of the abrasive particles.

Coumterbody 3 is fixed on the horizontal carrier disk 4; it is replaced at each measurement. So, equal initial conditions of contact interaction are assured between the butt surface 2 of the tested specimen and the abrasive surface 3. Near the friction path is located the nozzle of a vacuum pump enabling the suction of the waste particles during wear.

The horizontal carrier disk 4 and the abrasive surface 3 rotate with constant speed $\omega = const$ around their vertical axis. The speed of rotation is given by the electrical motor 5; the number of cycles N, respectively the friction way L, is read by the counter 6. Specimen 1 is mounted properly in the loading head 7 providing by means of leverage system the required normal load P in the gravity center of specimen 1. The average sliding velocity during friction is given through variation of the distance R between the axis of disk 4 and the axis of specimen 1.

The testing procedure goes in the following sequence:

- The surfaces of all specimens prepared in equal form and dimensions are subjected to mechanical treatment of three stages – rough, grinding and polishing up to the achievement of equal roughness $Ra = 0{,}4 \div 0{,}6\ \mu m$. This is necessary and compulsory condition in order to provide equal initial conditions at the subsequent comparative study or specimens' wear-resistance.
- By choosing the most popular integral parameter „mass wear", we have to weight specimen's mass before and after a given friction way (number of cycles of interaction) using electronic balance of the type WPS 180/C/2 with accuracy up to 0,1 mg. Before each measurement by the balance, the specimens are cleaned by a solution neutralizing the static electricity.
- Specimen 1 is mounted in the loading head 7 in a given position. The normal central load P is given through the leverage system.

The basic parameters of the study are as follows:

- *absolute mass wear* m, $[mg]$ - the destroyed mass of the surface layer of the specimen as difference between the mass of the specimen before and after the specified time of contact interaction.
- *mass wear rate* $\dot{m}$ $[mg/\min]$ - the destroyed mass of the surface layer during one minute time.
- *wear intensity* i - the destroyed thickness of the surface layer in a unity of friction way. It is a dimensionless quantity; if expressed through the destroyed mass, it can be calculated by the formula:

$$i = \frac{m}{\rho . A_a . L} \quad \left[\frac{kg.m^3}{kg.m^2.m} \right] \tag{1}$$

where:

ρ is the material density of the specimen - $\rho = 2{,}7.10^3 \left[kg/m^3 \right]$;

A_a is the apparent contact area of the interaction.

L is the way of friction calculated by the corresponding number of cycles of contact interaction N using the formula:

$$L = 2\pi.R.N \quad [m] \tag{2}$$

Here R is the distance between axis of rotation of the carrier disk and the center of mass of the specimen according to Figure 1.

- *absolute wear-resistance* I - a dimensionless quantity calculated as reciprocal value of wear intensity, i.e.

$$I = \frac{1}{i} = \frac{\rho.A_a.L}{m} \tag{3}$$

- *nominal contact pressure* $p_a, [N/cm^2]$, i.e. the normal load distributed on unity apparent contact area of interaction A_a, so

$$p_a = \frac{P}{A_a} \tag{4}$$

2.2 Experimental results

The described device and procedure have provided experimental results about wear, and wear rate depending on the number of cycles (friction time) at different contents of microparticles. Table 2 shows the parameters of the experimental study.

Table 2. Parameters of the experimental study

Apparent contact area A_a, $[m^2]$	1.10^{-4}
Nominal contact pressure p_a, $[N/m^2]$	$10{,}50.10^{-4}$
Average sliding velocity V, $[cm/s]$	15,96

Figures 2 and 3 show plots of the relationship of mass wear *m* and number of cycles N for various contents of microparticles of TiC in the case of casted (Figure 2) and thermally treated (Figure 3) Al alloys.

Figures 4 and 5 show plots of the relationship of mass wear *m* and contents of microparticles of TiC in the case of casted (Figure 4) and thermally treated (Figure 5) Al alloys.

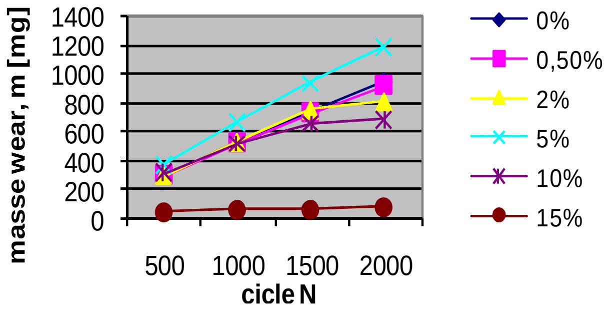

Figure 2. Mass wear versus number of cycles N at various % contents of TiC microparticles in the case of casted Al alloys

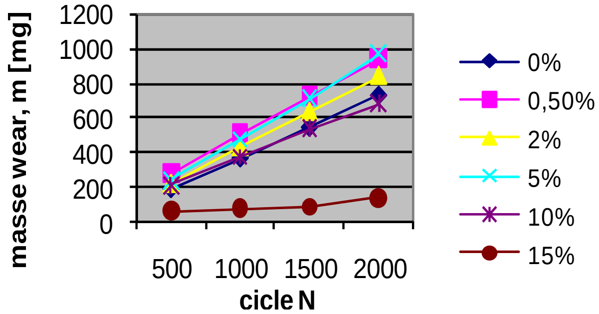

Figure 3. Mass wear versus number of cycles N at various % contents of TiC microparticles in the case of thermally treated Al alloys

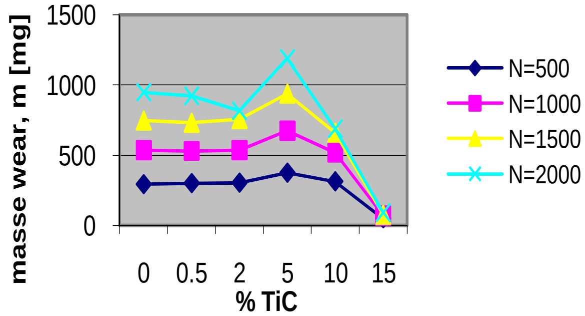

Figure 4. Mass wear versus % contents of TiC microparticles for different number of cycles N in the case of casted Al alloys

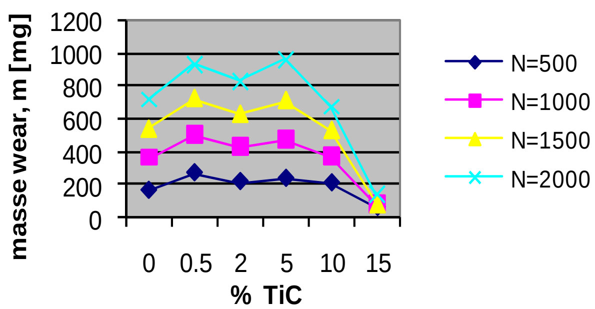

Figure 5. Mass wear versus % contents of TiC microparticles for different number of cycles N in the case of thermally treated Al alloys

Figure 6 show plots of the relationship of mass wear rate and contents of microparticles of TiC in the case of casted Al alloys specimens.

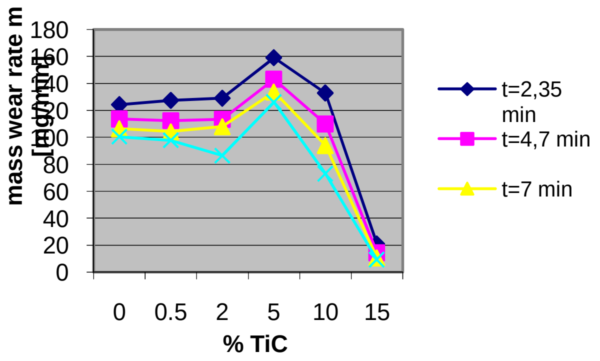

Figure 6. Mass wear rate $\dot{m}$ versus % contents of TiC microparticles for different time of wearing in the case of casted Al alloys

Table 3 gives the data about wear intensity and wear-resistance calculated according to equations (1) and (3) at $N = 2000$ cycles for all specimens

Table 3. Wear intensity i and wear-resistance I in the case of casted and thermally treated Al alloys

№	Code	Wear intensity i	Wear-resistance I
1	Л-0	$0{,}62.\ 10^{-5}$	$1{,}61.10^{5}$
2	Л-0,5	$0{,}6.\ 10^{-5}$	$1{,}67.10^{5}$
3	Л-2	$0{,}53.\ 10^{-5}$	$1{,}88.10^{5}$
4	Л-5	$0{,}78.\ 10^{-5}$	$1{,}28.10^{5}$
5	Л-10	$0{,}45.\ 10^{-5}$	$2{,}22.10^{5}$
6	Л-15	$0{,}06.\ 10^{-5}$	$17{,}24.10^{5}$
7	ТО-0	$0{,}48.\ 10^{-5}$	$2{,}1.10^{5}$
8	ТО-0,5	$0{,}62.\ 10^{-5}$	$1{,}62.10^{5}$
9	ТО-2	$0{,}55.\ 10^{-5}$	$1{,}81.10^{5}$
10	ТО-5	$0{,}64.\ 10^{-5}$	$1{,}57.10^{5}$
11	ТО-10	$0{,}45.\ 10^{-5}$	$2{,}24.10^{5}$
12	ТО-15	$0{,}092.\ 10^{-5}$	$10{,}86.10^{5}$

Figures 7 and 8 show diagrams of the wear-resistance for various % contents of TiC microparticles, respectively in the cases of casted (Figure 7.) and thermally treated (Figure 8.) Al alloys.

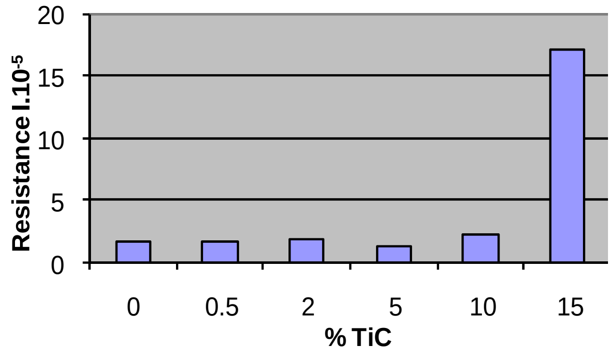

Figure 7. Diagram of wear-resistance at various % contents of TiC microparticles in the case of casted Al alloys

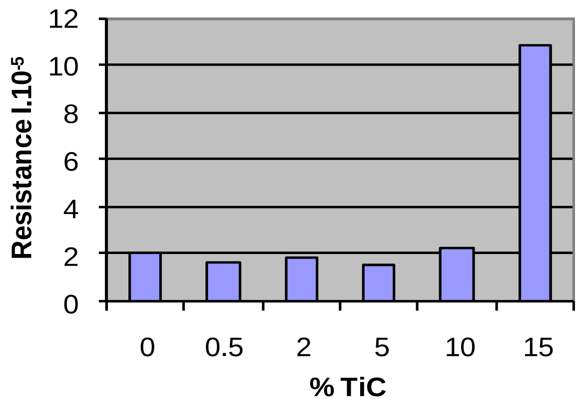

Figure 8. Diagram of wear-resistance at various % contents of TiC microparticles in the case of thermally treated Al alloys

2.3 Discussion on the experimental results

The analysis of the relationship mass wear versus friction way (number of cycles) shows clearly expressed linear proportionality (Figure 2 and Figure 3). Some nonlinearity appears for as-cast alloys with contents of microparticles 2wt% and 10wt% in the direction of wear decrease after $N = 1000$ cycles.

When the way of interaction corresponds to $N = 2000$ cycles and the wearing is in stationary regime, minimal wear values show as-cast specimens with 15wt% TiC - $m = 89\ mg$ (Figure 4). At the same particle contents and $N = 2000$ cycles wear is about 1.6 times higher for heat treated specimens, i.e. $m = 140{,}1\ mg$ (Figure 5).

The influence of the wt% contents of microparticles upon wear is ambiguous. In the case of as-cast alloys the presence of 0.5wt% and 2wt% TiC does practically not influence the amount of wear. At 5wt% wear sharply grows up and at $N = 2000$ the value of wear $(m = 1187{,}2mg)$ is 1.25 times higher than that of the as-cast specimen without microparticles $(m = 946{,}2mg)$- Figure 4. Strong decrease of wear is available at 15wt% *TiC*.

In the case thermally treated specimens (Figure 5) the minimal wear value is at $15\%\,TiC$ $(m = 140{,}1mg)$, however this value is higher than that of the as-cast alloys with the same wt% contents TiC $(m = 89mg)$.

Mass wear rate is a significant factor in the process of running-in in tribosystems; the higher rate assumes shortening of this period of adaptation and transition to stationary regime of operation. For as-cast specimens (Figure 6) at 15wt% *TiC* the wear rate is minimal - $\dot{m} = 9{,}4mg/\min$, and for heat treated specimens our results showed $\dot{m} = 14{,}9mg/\min$.

Wear-resistance is a complex parameter of the contact interaction in tribosystems. It is highly sensitive to a lot of factors – structure, contents and properties of surface layers; structure and properties of counterbody; presence of lubricant layers, wear debris, aggressive environment; dynamic parameters – sliding velocity, frequencies, vibrations, etc. Even with fixed parameters of interaction, the factor „time" determines in various degrees the value of wear, correspondingly the wear-resistance of different materials.

The analysis of the results in Table 3, Figures 7 and 8 demonstrates that the wear-resistance of as-cast specimens with 15wt% *TiC* particles is the highest one $\left(I = 17{,}24.10^5\right)$ and is 1.6 times higher than that of heat treated specimens with the same contents of microparticles.

3. CONCLUSION

- Procedure was developed and comparative study was carried out for wear and wear-resistance of composite aluminum alloys, as-cast and heat treated, reinforced by various weight contents of microparticles of *TiC* – 0.5%; 2%; 5%; 10%; 15%.
- Experimental results are obtained for the relationships of mass wear, wear rate, wear intensity and wear-resistance.
- The basic conclusion is that reinforcement of aluminum alloys by *TiC* microparticles leads to significant increase of the wear-resistance. The maximal wear-resistance in stationary regime of wearing showed as-cast alloys reinforced by 15wt% microparticles contents. Maximal wear rate under the same conditions exhibited alloys with 5wt% microparticles contents.

The obtained results involve a complex future study of the tribological parameters of these alloys, having in view their operation under various exploitation conditions of interaction.

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