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# MMCS BASED ON HYPOEUTECTIC AL-SI ALLOY: TRIBOLOGICAL PROPERTIES IN DRY SLIDING CONDITIONS

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**Abstract:** *This paper presents a short summary of the researches conducted in past few years concerning the MMCs with A356 Al-Si alloy matrix and different second phase. The results are divided in two groups. In the first group are the results that concern the influences of amount and size of reinforcement ($Al_2O_3$), and in the second group are the results that concern the influences of type of reinforcement ($Al_2O_3$ and SiC) and graphite.*

## 1. Introduction

Aluminium-silicon (Al-Si) alloys have attractive physical and mechanical properties. They are lightweight (app. 3x lighter then gray cast iron and steel), low costs production (with sand casting technology), easy to machine and have satisfactory mechanical properties with good recycling possibilities (up to 95 %). There are lots of applications of the Al-Si alloys, and one of them is replacing gray cast iron in engine cylinder blocks. Use of Al-Si alloys in this application has positive and negative aspects. Positive aspects are: reduction of engine mass, lower fuel consumption and reduced pollution; Shortcoming is, first of all, inappropriate tribological properties. Possible solutions for improving the Al-Si alloy tribological characteristics are: use of the tribological coatings, development of the new technologies of Al-Si alloys production (e.g. thixoforming) and production of the MMCs with Al-Si matrix [1,2].

## 2. Materials

The matrix material for all tested composites was A356 hypo-eutectic Al-Si alloy (EN AlSi7Mg0.3) with chemical composition shown in Table 1.

Table 1: Chemical composition (wt. %) of A356 Al-Si alloy

| Element | Si | Cu | Mg | Mn | Fe | Zn | Ni | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|
| Percentage | 7.20 | 0.02 | 0.29 | 0.01 | 0.18 | 0.01 | 0.02 | 0.11 | Balance |

Tribological test were conducted in two phases: In the first phase influences of amount and size of reinforcement were investigated, and in the second phase influences of type of reinforcement and graphite were investigated. The materials that have been tested are as follows.

Phase I – Influence of amount and size of reinforcement:

- MMC 1 – A356 + $Al_2O_3$ particles (3 wt. %; 12 µm), ref. as 3-12;
- MMC 2 – A356 + $Al_2O_3$ particles (10 wt. %; 12 µm), ref. as 10-12;
- MMC 3 – A356 + $Al_2O_3$ particles (10 wt. %; 35 µm), ref. as 10-35;
- Reference material – gray cast iron, ref. as SL 26.

Phase II – Influence of type of reinforcement and graphite:

- MMC 1 – A356 + $Al_2O_3$ particles (10 wt. %; 35 µm), ref. as 10-35;
- MMC 2 – A356 + SiC particles (10 wt. %; 39 µm), ref. as 10-39;
- MMC 3 – A356 + SiC (10 wt. %; 39 µm) and Gr (1 wt. %; 35 µm) particles, ref. as 10-39-1;
- Reference material – matrix alloy, ref. as A356.

Technology for producing the composites was compocasting method. Experimental procedure and apparatus used in compocasting processing are described and discussed elsewhere [3]. Composite specimens were thermally processed applying T6 heat treatment regime, which consists of solution annealing at 540 °C for 6 hours, water quenching and artificial aging at 160 °C for 6 hours. Microstructures of the tested materials have been presented and discussed elsewhere [3-6]. Hardness and other mechanical properties for the phase I materials have been presented and discussed in [4,5,7,8], and for the phase II materials in [6,9].

## 3. Tribological test procedures

Both tests were under dry sliding conditions, in ambient air at room temperature. The phase I tests were carried out on the standard pin-on-disc tribometer with cylindrical pins made of tested materials. The phase II tests were carried out on the ball-on-barrel tribometer with linear (reciprocating) movement. Moving body with cylindrical geometry was made of tested materials. Diagrams of the load, sample, counter body and the direction of movement for both tribometers are shown in Fig. 1. Main tribological test parameters are summarised in Table 2.

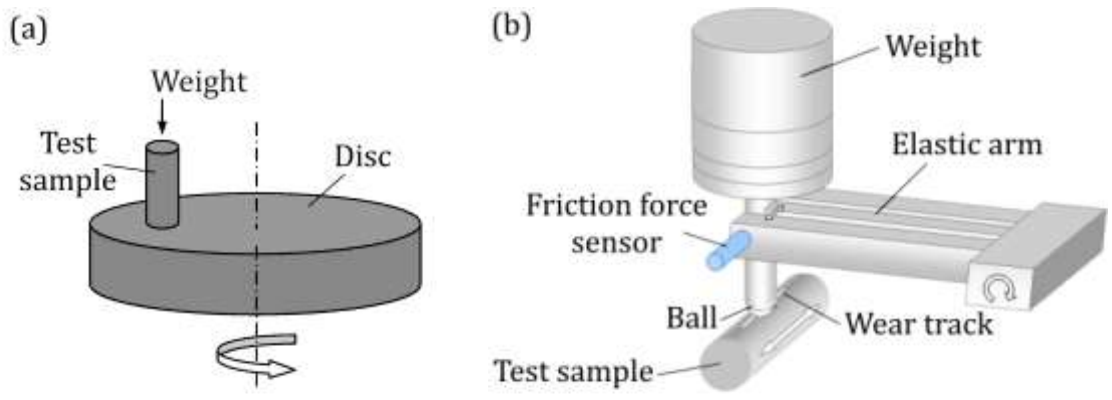


**Figure 1:** *Schematic drawing of tribometer used in: (a) phase I and (b) phase II*

Table 2: Main tribological test parameters

| Test parameter | Phase I values | Phase II values |
|---|---|---|
| Sliding speed | 1 m/s | 0.038 m/s (average) |
| Normal load | 1, 2, 3 and 4 MPa | 1 N |
| Sliding distance | 5000 m | 500 m |
| Counter body | disc (nodular gray cast iron) | ball (alumina) |

## 4. Results and discussion

### *4.1 Phase I – Influences of amount and size of reinforcement*

The steady-state coefficient of friction values did not change significantly with the change of load and one mean value per material could be accepted for the whole applied load interval (Fig. 2).

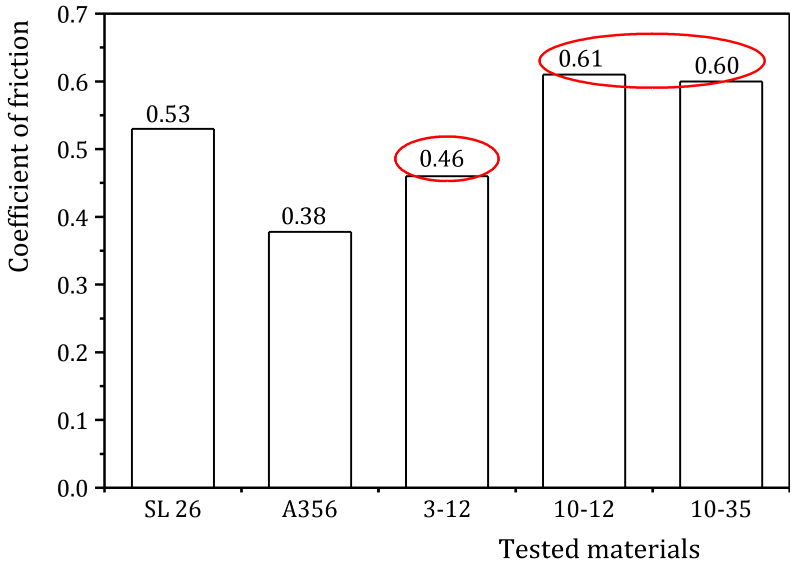


**Figure 2:** *The coefficient of friction average values of tested materials*

Attained values of coefficient of friction were in expected range for dry sliding conditions. Both composite materials with 10 wt. % of $Al_2O_3$ had higher values of the coefficient of friction than gray cast iron (SL 26), principally due to the presence of hard reinforcing particles. Confirmation for this statement is the value of the coefficient of friction obtained with composite containing 3 wt. % of $Al_2O_3$. In this case we have the same matrix and the same reinforcement but in lower amount, which induced lower coefficient of friction.

The wear rates (calculated for the steady-state period) at different loads are presented in Fig. 3. Tendency for all materials was the same, i.e. with the increase of specific load the wear rate also increases.

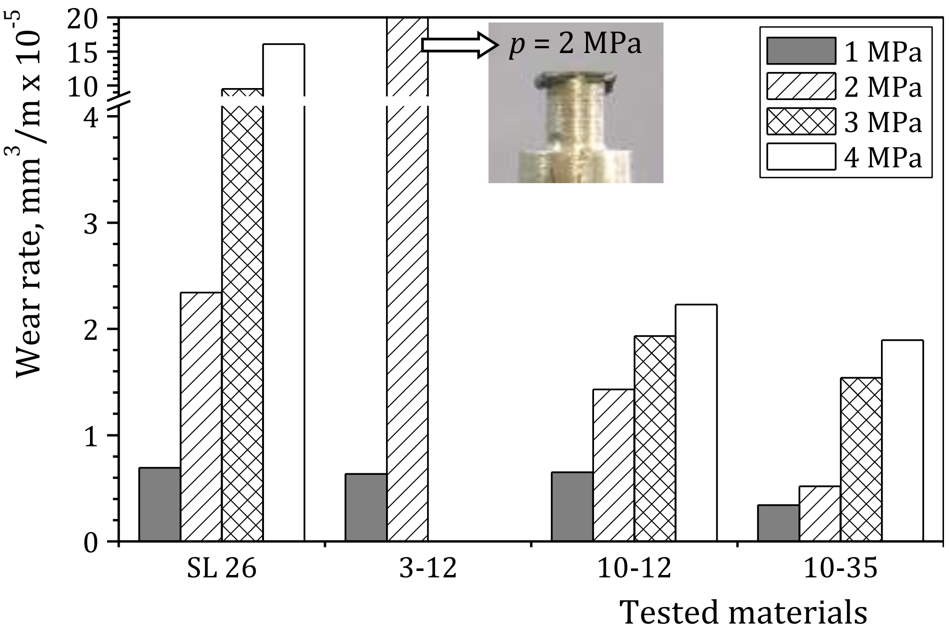


**Figure 3:** *Wear rates of the tested materials for different specific loads*

Comparison of the tested materials, by wear resistance, showed that 3 wt. % of $Al_2O_3$ was enough just for loads up to 1 MPa while both composites containing 10 wt. % of $Al_2O_3$ could be accepted as a possible substitution for the gray cast iron. Composite 10-35 showed the highest adhesive wear resistance in dry sliding conditions. For low loads bigger size (35 μm) of $Al_2O_3$ decreased the wear rate more than the smaller size, and for high loads the effect is less pronounced i.e. the wear rate starts to grow.

After the visual inspection, analysis of the worn surfaces was performed by scanning electron microscopy (SEM). At lower loads (1 and 2 MPa) gray cast iron samples were not in full contact with the counter body, and basic lamellar structure of the material could still be clearly noticed. At higher loads more intensive abrasive wear starts. Adhesive wear also occurs due to the presence of high pressures and contact temperatures. Worn surfaces of both composites containing 10 wt. % of $Al_2O_3$ showed similar appearance indicating adhesion as dominant wear mechanism. At lower loads (1 and 2 MPa) presence of transferred counter body material to the samples could be noticed.

Wear products were also analysed by SEM. Morphology and size of wear products for all tested materials were similar. Mainly sharp edge, plate-like particles prevail, without any visible grooves on them, which is characteristic for adhesive wear. Only in case of composite 3-12 presence of the rod-like particles, longer than 50 μm were noticed, which indicates existence of severe wear. Dimensions of the wear products in case of all other materials were app. 10 μm (some of them were 20 to 30 μm in diameter, but less than 50 μm, i.e. severe wear did not occur).

*4.2 Phase II – Influences of type of reinforcement and graphite*

Obtained average steady-state values of coefficients of friction and wear rates are presented in Fig. 4. Values of coefficients of friction were in expected range for light metals in dry sliding conditions, and all tested materials showed very similar values.

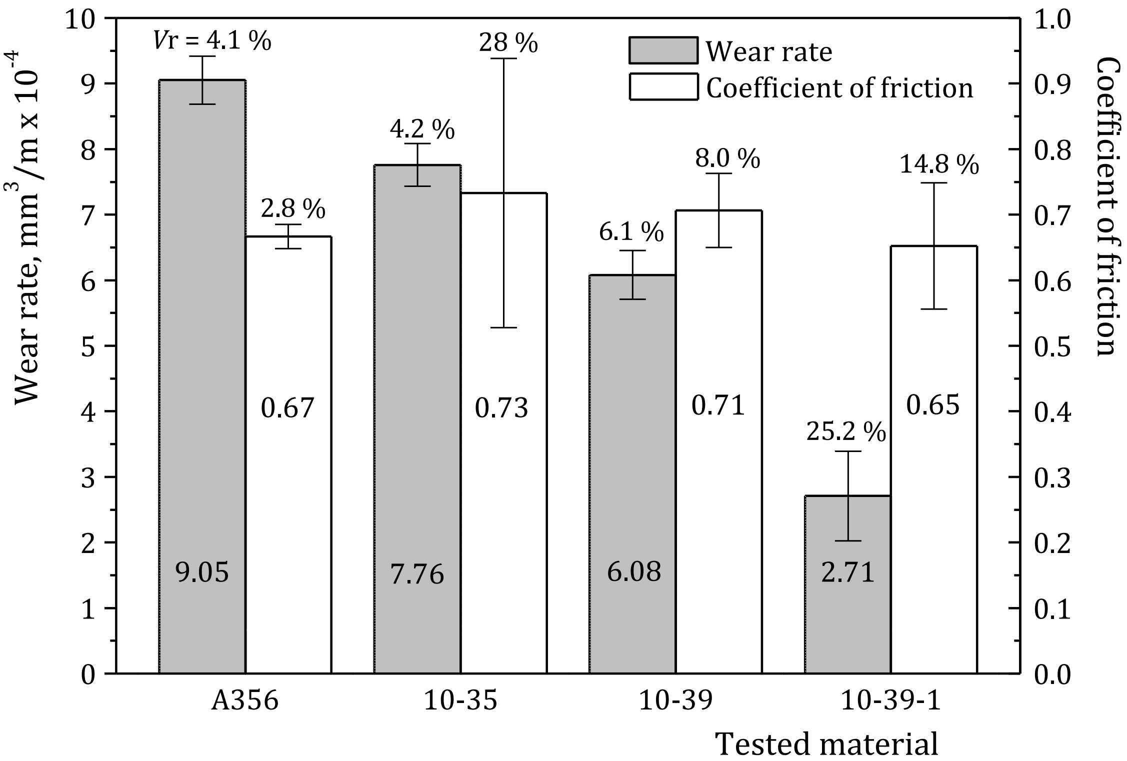


**Figure 4:** *Wear rate and coefficient of friction values of tested materials*

The A356 Al-Si alloy showed the smallest variation of results since it was the most homogeneous material. This material also showed the lowest wear resistance. Higher wear resistance of composites reinforced with SiC particles (10-39 and 10-39-1) in relation to composite reinforced with $Al_2O_3$ particles (10-35) can be explained by favourable arrangement of SiC reinforcing particles in the composite matrix, i.e. clusters B [10]. Addition of the graphite particles in composite 10-39-1 reduced wear rate and coefficient of friction. Since the presence of graphite was small (only 1 wt. %) this should be considered with caution and only noticed as a possible trend of behaviour.

SEM analysis of worn surfaces confirmed that the adhesive wear was dominant type of wear. Protruded SiC particles (more obvious for 10-39-1) protected the matrix and lower the wear rate. Presence of $Al_2O_3$ particles on the surface was not noticed. Morphology and size of wear products for all tested materials were similar. Mainly sharp edge, plate-like particles prevail, which is characteristic for adhesive wear.

The wear products of A356 matrix alloy and composite 10-35 showed variations in size and in some cases individual particles, larger than 50 μm in diameter, could be detected. This indicates existence of severe wear. The maximum sizes of wear products for composites 10-39 and 10-39-1 were smaller, with maximum particles sizes of app. 20 μm in diameter.

## 5. Conclusions

- The composite materials with better tribological properties in relation to matrix alloy can be obtained by compocasting process.
- For the investigated conditions (dry sliding, adhesive wear), some composites could be an adequate substitution for gray cast iron as a standard material for cylinder blocks.
- A hybrid composite (with SiC and Gr particles) showed the lowest values of wear rate and coefficient of friction in dry sliding conditions.
- Addition of graphite (1 wt. %) improved tribological properties but an optimal amount should be determined for each application.

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