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# IMPROVEMENT OF THE TECHNICAL AND OPERATIONAL CHARACTERISTICS OF ZA-27 ALLOYS REINFORCED WITH SIC AND $AL_2O_3$

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## 1. Introduction

The ZA-27 alloy belongs to the group of zinc–aluminium alloys, which are well known for their high strength and wear resistance, good dimensional stability, and relatively low cost compared to other materials with similar technical and operational characteristics. Composites such as ZA-27+$Al_2O_3$+SiC are increasingly applied in technical and tribo-mechanical systems. These alloys have found wide application in mechanical engineering and transportation, particularly in the automotive industry for brake components, engine parts, and steering systems, as well as in aerospace applications and machine tools, where elements are exposed to increased friction and wear [1, 2].

By combining ZA-27 with reinforcements such as $Al_2O_3$ (aluminium oxide) and SiC (silicon carbide), composites with exceptional properties are obtained. $Al_2O_3$ is used as a reinforcement in composites due to its high hardness and wear resistance. This material significantly improves the mechanical properties of the composite, such as strength, impact resistance, and abrasion resistance. SiC is an extremely hard substance with high heat and wear resistance. When combined with ZA-27, SiC contributes to the composite's thermal stability and provides additional mechanical durability [1, 2].

Numerous studies and research papers highlight the advantages of these alloys in practical applications compared to many other materials. The focus of this study is not on comparing ZA-27 alloys with other materials, but rather on examining the ZA-27 alloy with reinforcements, specifically how SiC- and $Al_2O_3$-based reinforcements influence the coefficient of friction and penetration force during experiments.

The tribological properties of materials are influenced by several factors, including applied load, sliding speed, lubrication conditions and type of lubricant, as well as the surrounding environment in which the experiment is conducted. In the case of composites with reinforcements, the percentage of reinforcement also plays a key role. However, an increased reinforcement content does not necessarily guarantee improved properties; instead, the characteristics also depend on the fabrication method and the degree of homogeneity achieved. A more uniform microstructure ensures consistent performance across the entire surface. Research findings [3] have shown a significant reduction in the coefficient of friction for reinforced materials compared to the base alloy. Optimal results were obtained under a load of 20 N (load range: 20–80 N) and a sliding speed of 1 m/s (speed range: 1–2 m/s), where minimal wear and the lowest coefficient of friction were recorded. Notably, the best results were achieved with a 5% reinforcement content, with variations tested between 1% and 5% [3].

The fabrication method also significantly affects the properties of such composites. These materials are most commonly produced by either sintering or compo-casting. Increasing the sintering temperature has been found to reduce wear and improve friction resistance, highlighting the potential for application of these materials in demanding industrial environments. The results confirm that high-temperature sintering substantially enhances the tribological properties of the material. These findings may be of great importance for the development of new materials in engineering and manufacturing, where wear resistance is critical [4, 5].

Several studies hypothesize that the addition of SiC and graphite enhances the wear resistance of composites under dry sliding conditions, since these solid particles can reduce friction and wear compared to unreinforced ZA27 alloy. Experimental results confirm that composites reinforced with SiC and graphite exhibit significantly reduced wear compared to the base ZA27 alloy, thereby supporting the hypothesis regarding improved tribological properties. This analysis highlights the potential of ZA27/SiC/Graphite composites for industrial applications in environments where wear resistance is critical. Another important finding is that composites containing graphite demonstrated much better results than those without, as graphite acted as a solid lubricant [6, 7].

In addition to dry sliding tests, investigations including lubrication with oil at the contact interface have also been carried out. These results confirm the positive influence of nano-graphite on the tribological performance of ZA27 alloys under lubricated conditions, opening new opportunities for industrial applications [6, 7].

Furthermore, results have shown that the strength and hardness of aluminium alloys increase with the addition of $Al_2O_3$, while the wear rate decreases. This emphasizes the role of $Al_2O_3$ as a reinforcement in aluminium-based composites, which may be highly relevant for the development of more efficient braking systems in the automotive industry [8].

## 2. Experiment

The experiment was carried out using a CSM+ Instruments nano-tribometer, as shown in Figure 1.

The tests were performed under dry sliding conditions, where the contact pairs consisted of the prepared composite samples obtained by the compo-casting method and a counter ball. The ball was made of Inox 440C stainless steel, with a hardness of 62–64 HRC and a diameter of 1.5 mm. In addition, an optical microscope, presented in Figure 2, was used as part of this investigation. The experimental plan is summarized in Table 1.

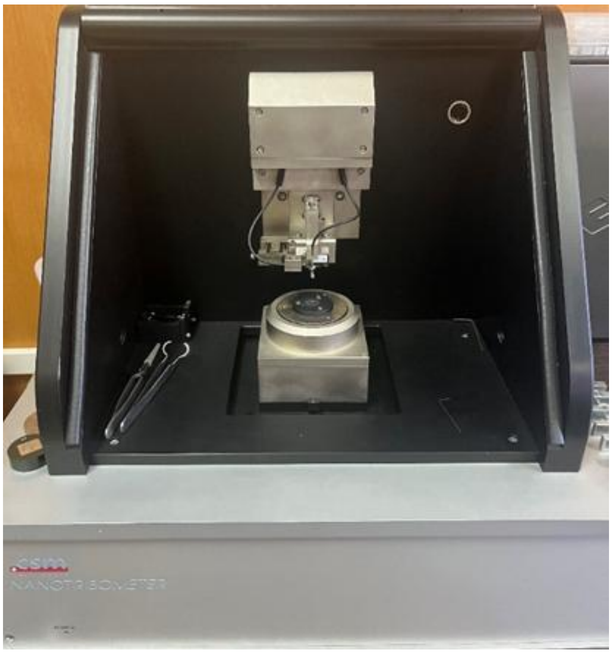

**Fig. 1.** Nanotribometer CSM + Instruments.

**Fig. 2.** Optical Microscope.

Table 1 presents the material composition in one column and the testing conditions in the other.

**Table 1.** Experimental Plan.

| Materials | Conditions |
|---|---|
| ZA-27+0.5%$Al_2O_3$+5%SiC | Counter ball:<br>Inox 440C,<br>62-64 HRC,<br>diameter 1.5 mm.<br><br>Experimental parameters:<br>Sliding speed v=8 m/s,<br>Load F= 200mN,<br>Number of cycles n=500.<br><br>Wear track radius:<br>r=2 mm, r=3 mm, r=4 mm<br><br>Reinforcement size:<br>$Al_2O_3$ - 20-30 nm<br>SiC - 40 µm |

## 3. Results and discussion

After the completion of the experiment, which consisted of tribo-pairs made of a composite block and a steel ball, under constant load, sliding speed, and a fixed number of wear cycles, but with varying wear track radii (r = 2 mm, r = 3 mm, r = 4 mm), the results were obtained as shown in Figures 3, 4, and 5. Figure 6 presents the histogram of the coefficient of friction.

Figure 3 shows the diagram of the coefficient of friction and penetration force under the following experimental parameters: sliding speed v = 8 m/s, load F = 200 mN, number of cycles n = 500, and wear track radius r = 2 mm.

**Fig. 3.** Diagram of the coefficient of friction and penetration force under the experimental parameters: sliding speed v = 8 m/s, load F = 200 mN, number of cycles n = 500, and wear track radius r = 2 mm.

Figure 4 presents the diagram of the coefficient of friction and penetration force under the following experimental parameters: sliding speed v = 8 m/s, load F = 200 mN, number of cycles n = 500, and wear track radius r = 3 mm.

Figure 5 shows the diagram of the coefficient of friction and penetration force for the parameters: sliding speed v = 8 m/s, load F = 200 mN, number of cycles n = 500, and wear track radius r = 4 mm.

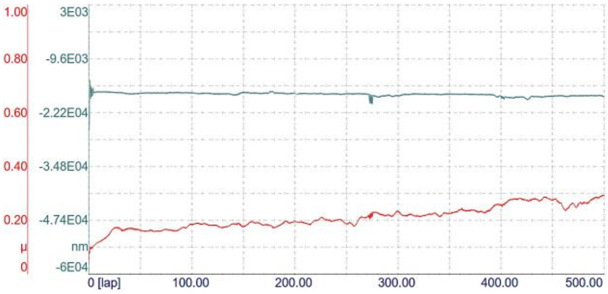

**Fig. 4.** Diagram of the coefficient of friction and penetration force under the experimental parameters: sliding speed v = 8 m/s, load F = 200 mN, number of cycles n = 500, and wear track radius r = 3 mm.

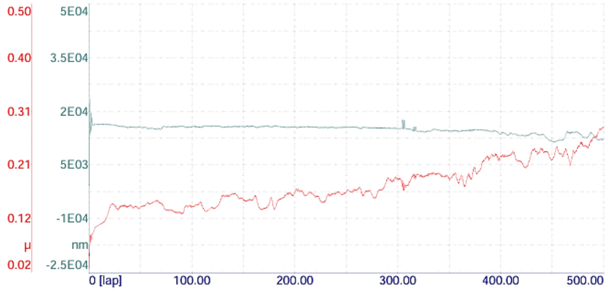

**Fig. 5.** Diagram of the coefficient of friction and penetration force under the experimental parameters: sliding speed v = 8 m/s, load F = 200 mN, number of cycles n = 500, and wear track radius r = 4 mm.

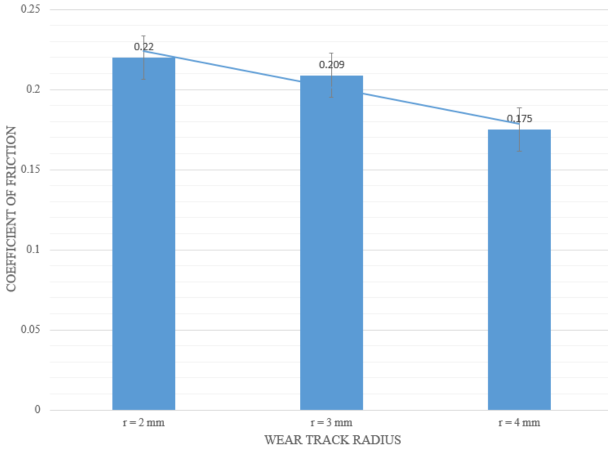

**Fig. 6.** Histogram of the coefficient of friction.

The specimens exhibited similar penetration depths across all three experiments, but their coefficients of friction showed slight variations. In all cases, the coefficient of friction increased slightly with the number of cycles. The sample with a wear track radius of 4 mm demonstrated the most irregular diagram of the coefficient of friction, most likely due to pronounced adhesion as one of the dominant wear mechanisms. However, this same sample also recorded the lowest average coefficient of friction.

Wear is governed by multiple interacting mechanisms, which makes its behavior highly complex. When the wear track radius was small, the primary process was two-body abrasion. With an increase in radius, the wear scars became wider and adhesion effects intensified, producing transfer films and micro-welded particles. The progression of wear was also strongly dependent on the number of cycles, since repeated loading promoted material fatigue and the gradual stabilization of transfer layers. For long-term service of engineering components, both of these factors must be taken into account. A clear understanding of such phenomena is key to improving material processing methods as well as ensuring reliable performance in industrial use [3, 5, 6, 8].

The diagrams show that penetration force remained nearly constant with minimal variation, while the coefficient of friction in the third case (r = 4 mm) was the lowest. In contrast, the first two samples exhibited similar but considerably higher coefficients of friction. For the first sample, the coefficient of friction was 0.220 (r = 2 mm); for the second, it was 0.209 (r = 3 mm); and for the third, it was 0.175 (r = 4 mm). As the wear track widened, the actual contact area increased. In materials capable of sustaining higher loads, this led to a redistribution of stress over a larger contact zone, thereby reducing local pressure. With lower local pressure, the tendency toward adhesion and micro-welding decreased, ultimately resulting in a reduced coefficient of friction.

## 4. Conclusion

The results highlight the complex nature of wear and its mechanisms. Two-body abrasion was dominant in samples with smaller wear track radii, while increasing the radius led to larger wear scars and more pronounced adhesion, resulting in the formation of transfer layers and micro-welded particles. The number of cycles had a significant influence on the stability of the wear process, suggesting that material fatigue and the formation of stable transfer layers must be considered in long-term operating conditions of technical systems. Understanding these factors is essential for optimizing both the manufacturing and exploitation of materials, as well as their application in industrial environments.

It is also important to account for surface imperfections resulting from the compo-casting method of sample preparation, as these imperfections significantly influence both penetration force and the coefficient of friction. Sudden jumps and drops in the diagrams of friction coefficient and penetration force may indicate that the ball encountered either a porous region of the material or a zone of higher hardness compared to the surrounding surface.

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