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Corrosive-Erosive Studies of Al/Al₂O₃ Metal Matrix Composites

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ABSTRACT: The present research work attempted to analyze the effect of Al₂O₃ on the Corrosive-Erosive properties of the resulted MMCs considering the mismatches between the properties of the matrix and reinforcement. The MMCs were prepared by liquid metallurgy technique for varying percentages of reinforcement in steps of 0, 5, 10, 15 and 20% by weight. The corrosive-erosive wear tests were carried out on a corrosive-erosive wear tester designed and fabricated for this study. The corrosive-erosive wear rate of the composites greatly decreased due to the reinforcing particles (Al₂O₃).

KEYWORDS: Al₂O₃, MMCs, Corrosion, Erosion, Wear

I. INTRODUCTION

The customized specific properties of materials for better overall performance are so great and diverse that no material can satisfy the conflicting requirements of constructive properties. These reasons have led to the research on materials, which can satisfy the varying demands of the different industries. There are more than eighty thousand materials represented in the market, and this figure is rapidly increasing. Advanced materials are being developed to an increasing extent [1]. Among these materials, one finds composite being used prominently. These outstanding benefits of composite materials are that they can be tailored to produce various combinations of stiffness and strength [2, 3]. This ability to engineer materials with specific properties for particular applications represents a great potential advantage of composites. It is also possible to selectively reinforce particular areas of components, thus improving the properties of materials only in that area, which is truly necessary [4].

II. LITERATURE SURVEY

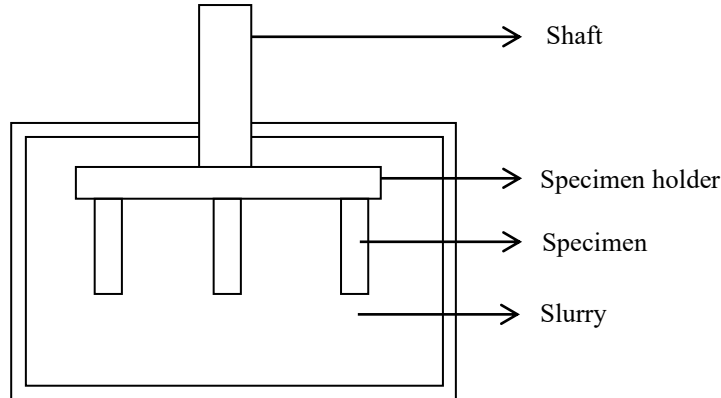
Due to the complexity of the MMCs, a better understanding of the residual stresses in these materials is essential. The demand for high strength and stiffness and low-density materials has laid considerable importance to the manufacturing aspects of particle-reinforced metal matrix composites (MMCs). MMCs are potential materials for technological applications because they exhibit higher stiffness [5-7], lower thermal expansion [8, 9], lower thermal conductivity [10, 11], better damping properties [12, 13], higher hardness [14], and higher wear and corrosion resistance [15-21] than conventional alloys. MMCs are increasingly being used in many engineering applications, in products such as automobile parts (i.e. Piston liners, clutches, pulleys, etc.), aircraft components, sports goods, etc.

III. EXPERIMENTAL PROCEDURE

The present study makes use of the liquid metallurgy technique. Al6061, which exhibits excellent casting properties and reasonable strength, was used as the base alloy. This alloy is best suited for mass production of lightweight metal castings. Al₂O₃ is a ceramic material used for high-temperature applications because of its high melting point, lower density, and capacity to retain high strength at elevated temperatures. The MMCs were prepared by varying the percentages of reinforcement in steps of 0, 5, 10, 15 and 20% by weight.

**Fig. 1. Corrosive-Erosive Wear Tester**

The corrosive-erosive wear tests were carried out on a corrosive-erosive wear tester designed and fabricated for this study as shown in Fig. 1. The specimens of diameter 6 mm and length 15 mm were tested. Three specimens were immersed at a time (120° apart in the corrosion medium) for a given set of experimental conditions. The specimen holder consisted of a rotating disc with a provision to insert three specimens at 120° apart circumferentially at 0.1 m radius, to maintain the dynamic balance. Fig. 2 shows the setup of the corrosive-erosive wear tester. The holder was rotated at 1440 RPM using an electric motor to maintain the sample speed of 5 m/s. The average values of the material removal were computed, and travel distance was varied by varying the duration of the test to obtain sliding distances in the range of 100 km. Three specimens were tested for each set of test parameters.

**Fig. 2. Setup of the corrosive-erosive wear tester**

The composition of the slurry was varied by changing the content of the SiC particle (90-150 μm) from 0 to 30 wt.% (interval of 10 wt.%) in the H_2SO_4 liquid concentrations of 0.001, 0.01, 0.1 and 1.0 N. Fresh slurry was used for each of the test conditions. Weight loss was determined by weighing the specimen before and after the tests. The specimens were ultrasonically cleaned in acetone before weighing. Though the corrosion-erosion wear was measured as the weight loss, the results are expressed in terms of wear rate.

IV. EXPERIMENTAL RESULTS

Figure 3 shows the variation in the corrosion-erosion rate of Al/ Al_2O_3 composites with the amount of SiC (wt. %) in the slurry using tap water and H_2SO_4 of normality 0.001N at a sliding distance of 100 km. All the curves started at almost low wear rates, which was due to a very low wear rate in tap water. The wear rates of both Al and Al composites significantly increased with the increasing volume fraction of SiC particles. But, the nature of the curve has changed [66]. The presence of solid suspended particles (SiC) in the slurry increased the extent and wear rate of overall material loss of the samples (0-20 wt.% alumina composites) by 5 to 8 times for 30 wt.% SiC content in slurry

compared to 0 wt.% SiC content. However, the wear rate was decreased for composites by 2.02 to 3.32 times for 20 wt.% alumina compared to Al alloy.

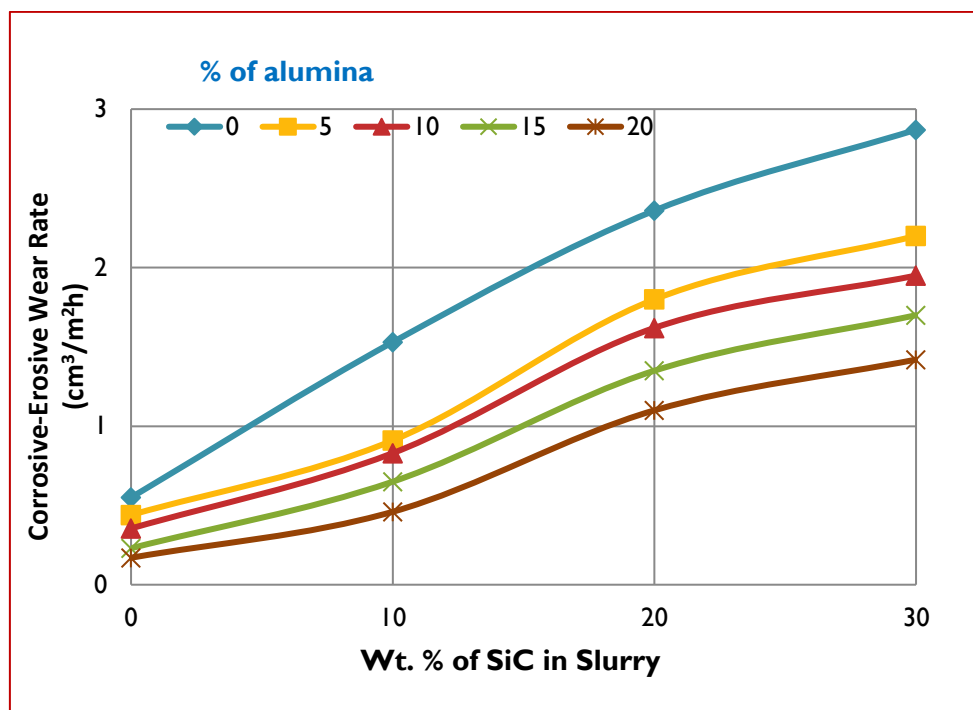


Fig. 3. Corrosive-Erosive wear rate for Al alloy and Al/Al₂O₃ composites with varying wt.% of SiC in slurry composition

Figures 4 and 5 show that the wear rate of each material increases with the concentration of H₂SO₄, as expected. The corrosion attack had a stronger tendency to penetrate more deeply as the concentration of the H₂SO₄ solution increased from 0.001 to 1 N. It was found that the wear rate for 0 wt.% of SiC has increased by 3.09 to 4.58 times for 1N compared to 0.001N and for 30 wt.% of SiC, it has increased by 2.46 to 3.48 times for 1N compared to 0.001N. The corrosive-erosive wear rate of the composites greatly decreased (2.5 to 4.4 times for 0 wt.% of SiC and 1.7 to 2.92 times for 30 wt.% of SiC) due to the reinforcing particles (Al₂O₃) preventing the intrusion of the erodent and blocking the propagation of micro-cracks. The same trends were observed for different concentrations of the H₂SO₄ environment.

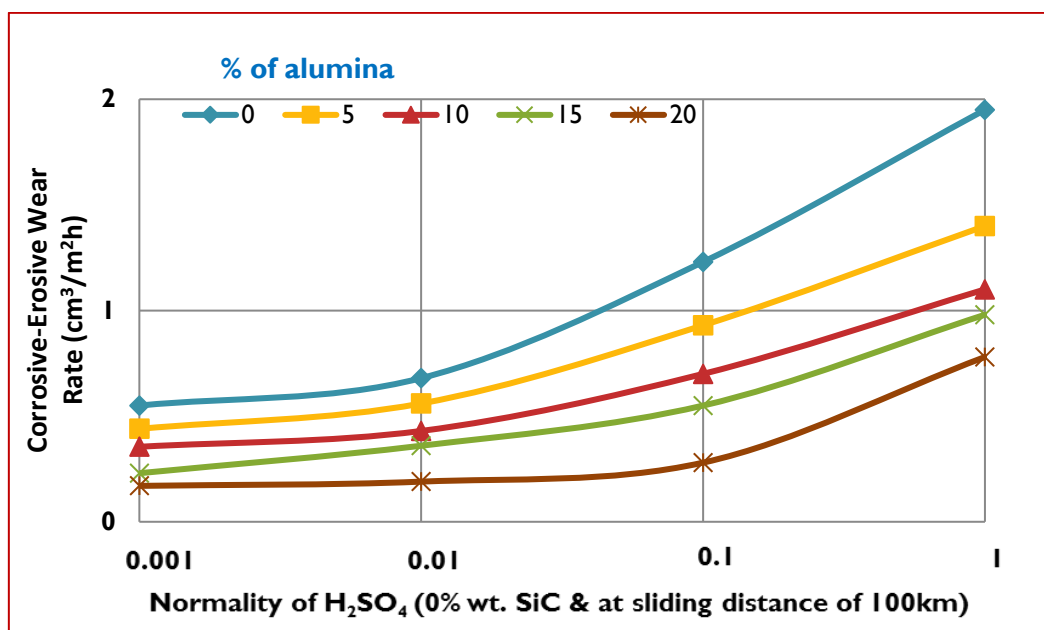


Fig. 4. Corrosive-Erosive wear rate for Al alloy and Al/Al₂O₃ composites with varying concentrations of H₂SO₄ in slurry composition (0% wt. SiC & 100 km sliding distance)

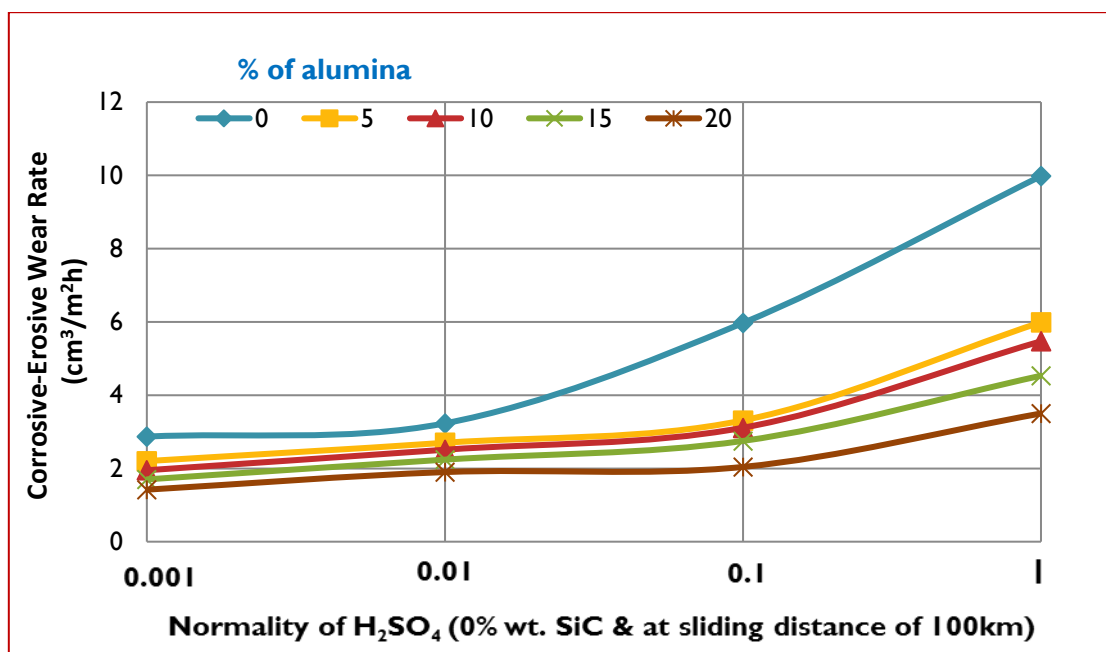


Fig. 5. Corrosive-Erosive wear rate for Al alloy and Al/Al₂O₃ composites with varying concentration of H₂SO₄ in slurry composition (20% wt. SiC & 100 km sliding distance)

To study the pure corrosive, pure erosive and corrosive-erosive mechanisms of the Al matrix alloy and Al/ Al₂O₃ composites, scanning electron microscopy was used. SEM of the corroded-eroded surfaces of both the matrix alloy and the composites was carried out under different conditions are shown in Fig. 6.

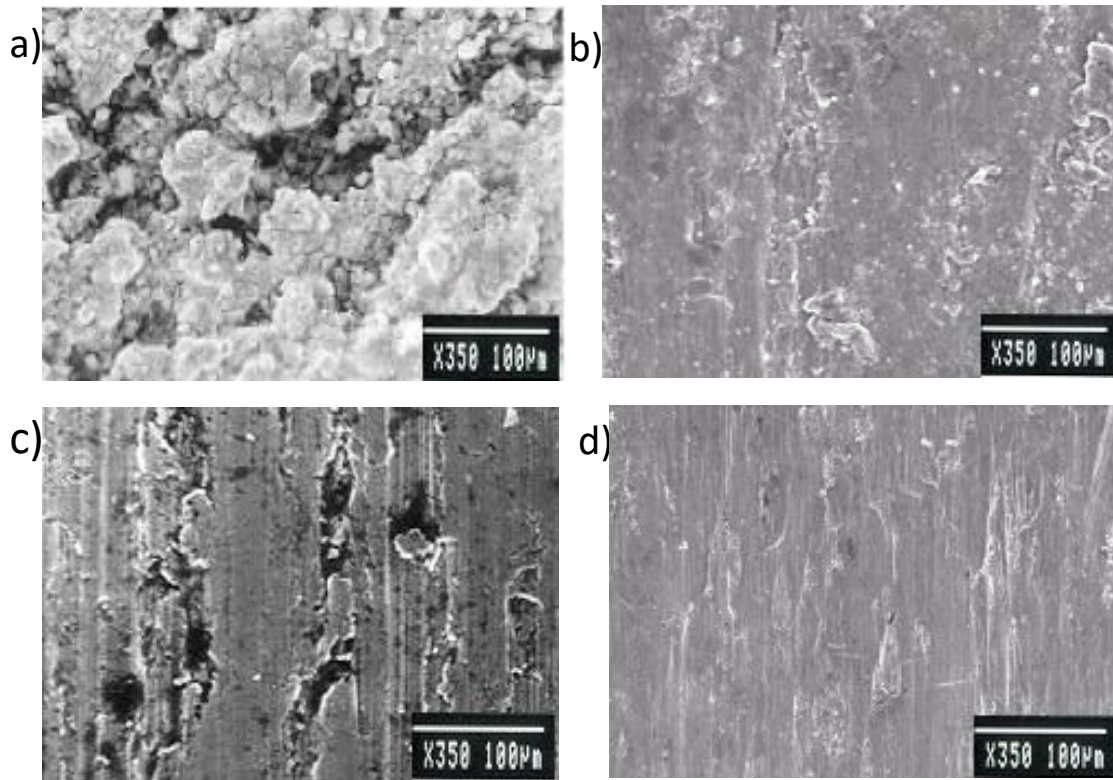


Fig. 6. SEM images of (a) corroded surface of Al alloy, (b) eroded surface of Al alloy, (c) corroded eroded surface of Al alloy and (d) corroded eroded surface of Al/20 % Al_2O_3 composites

Corrosion in 1N H_2SO_4 has shown corrosion only at the grain boundary in the alloy as shown in Fig. 6 (a). The presence of micro-cracks along the grain region was also seen in the matrix alloy.

The scanning electron micrographs of the worn surface (pure erosive) of the Al matrix alloy is shown in Fig. 6 (b). For abrasion of SiC, the wear grooves, and plastic ploughing characterized the worn surface of the specimen. The severity of micro-cutting and associated plastic deformation relatively increased. The higher erosive wear was due to the rapid impingement of solid particles (SiC) in the slurry.

In addition to erosive wear, the specimen also suffered from corrosion in a sulphuric acid solution. This was observed in Fig. 6. (c). The degree of surface damage regarding corrosion, pitting and cracking in the matrix enhanced significantly when the tests were conducted in 1N H_2SO_4 + 30 wt. % sand (SiC) environment.

Fig. 6. (d) shows that after the surface was cut off, ploughed or impacted in the erosion process, a certain volume of the material was left undeformed. Erosion caused exposure of greater areas of the specimen to the corrosive media. The greater the area of exposure, the greater is the corrosion. On the other hand, the surface of the material after corrosion became porous, which was weaker, and the cutting, ploughing or impact of the suspended particles was easier and more effective. Thus, corrosion accelerates erosion.

These observations led to the conclusion that the effect of combined erosion-corrosion and abrasion by the slurry flow was responsible for the higher loss of specimen material. The action of abrasion damaged the passive film on the surface of the material, which accelerated the corrosion. Moreover, the corrosion attack further aided the abrasion process.

V. CONCLUSION

Based on this study, the following conclusions have arrived. The presence of solid suspended particles (SiC) in the slurry increased the extent and wear rate of overall material loss of the samples (0-20 wt.% alumina composites) by 5 to 8 times for 30 wt.% SiC content in slurry compared to 0 wt.% SiC content. But, the wear rate was decreased by 2.02 to 3.32 times for 20 wt.% alumina compared to Al alloy. It was found that the wear rate for 0 wt.% of SiC in slurry has increased by 3.09 to 4.58 times for 1N compared to 0.001N and for 30 wt.% of SiC, it has increased by 2.46 to 3.48 times for 1N compared to 0.001N. The corrosive- erosive wear rate of the composites greatly decreased (2.72 to 5 times for 0 wt.% of SiC and 1.7 to 2.92 times for 30 wt.% of SiC) due to the reinforcing particles (Al_2O_3).

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