

Investigating the effect of reinforcement on corrosive erosive properties of Al/Nanoclay Metal matrix composites

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Abstract: -- Nano-metal-matrix composites (NMCs) are novel composite materials in which nano-phase such as nano-particles, nano-rods, nano-structured materials are reinforced with metals or alloys to improve the physical, mechanical, wear and other properties. In the present study, Al6061 alloy has been chosen and used as the matrix material and nanoclay as the reinforcement.

Composites were prepared by using liquid metallurgical route (stir casting method) nanoclay particle content was increased from 0 to 20 % in steps of 5% by weight. Corrosive erosive wear test was conducted on Al-Nanoclay metal matrix by corrosive-erosive wear tester. Three specimens are tested at a time for constant conditions as per ASTM standards, the matrix material without the reinforcements was also subjected to the wear tests to achieve a comparing with the composite material with different percentages of nanoclay.

From the results it is observed that, Corrosive erosive wear rate varies marginally at lower speeds but increase sharply at higher speed. The corrosive wear rate logarithmically increased with the increasing concentration of the corrosive medium. The composites attained better corrosive-erosive (Vce) wear resistance than the matrix alloy irrespective of the test condition. The erosive-corrosive wear rate of the specimen have an exponential relation with the HCL concentration and erosion speed of the slurry, Corrosive wear was the predominant mechanism of material removal in the corrosion and abrasion modes of wear.

The effect of abrasive particles and corrosion medium on the wear behaviour of the composite is explained experimentally and compared with ascast aluminium alloy

Keywords: 61, NMCs, Corrosive wear, wear resistance

1. INTRODUCTION

Recently, MMCs reinforced by Nanoclay particles, whiskers and short fibers, have performed well in the frictional and wear region for its super wear resistance, high strength and low density. But because of its high cost and price, the lack of stability of property, the application development of composite has met great resistance [1]. Lot of research work has been conducted on Al NMCs in research centers and industries in the last decade which led many Al NMCs to find application in different fields [2-3]. The Al NMCs have not only mechanical properties, but also functional properties along with high structural, wear resistance, thermal and electrical properties.

There are many challenges in Al NMCs, one of them is compatibility between reinforcement and matrix alloy, this leads to controlling of the reinforcement distribution within the matrix alloy [4]. Zhao et al. [5] showed that both

mechanical and deformation behaviour of Al NMCs. Thus, further work need to be done in order to lower the expense of the advanced composites. With the development in the fabrication technology, new reinforcements should be found and adopted to lower the expense [6-7]. In view of the above description, an attempt has been made to study the mechanical properties of the composites under a 40 KN capacity servo hydraulic universal testing machine, for various reinforcement sizes. The composites were subjected to tensile and compression tests. This study examines the effect of Nanoclay wt% on the mechanical properties of aluminium metal matrix composites.

In industries several critical conditions such as high temperature, impacts, abrasive wear etc. made them working towards new materials such as nanoparticulate reinforced composites. Many researchers suggested that use of NMCs is a highly promising way to serve successfully in these conditions. [8-9] The Orowan equation shows that nano size reinforcement is highly advantageous than the macro size reinforcement for

corrosive erosive applications. Only small amount of nano size reinforcement is enough to give higher corrosive wear resistance to the matrix alloy [10]

2. EXPERIMENTAL DETAILS

Al-6061 was used as the matrix material because of its excellent casting properties and reasonable strength. This alloy is best suited for mass production of lightweight metal castings.

The nanoclay of 30, 50 and 70 nm size were used as the reinforcement and the nanoclay content in the composites was varied from 5 to 15% in steps of 5% by weight. Liquid metallurgy technique was used to fabricate the composite materials in which the clay particles were introduced into the molten metal pool through a vortex created in the melt by the use of an alumina-coated stainless steel stirrer. The coating of alumina on the stirrer is essential to prevent the migration of ferrous ions from the stirrer material into the molten metal. The depth of immersion of the stirrer was about two-thirds the depth of the molten metal. The stirrer was rotated at 550 rpm. The pre-heated (500 °C) nanoclay particles were added into the vortex of the liquid melt which was degassed using pure nitrogen for about 3 to 4 min. The resulting mixture was tilt poured into preheated permanent moulds to obtain casting. The corrosion tests was conducted using the conventional weight loss method according to ASTM G67 standards, Specimens dimension 20mm diameter and 20mm length with smooth finish, Sliding distances in a range of 0.1 – 100 km was used in the test.

3. CORROSIVE- ERROSIVE TESTS (ASTM G67)

The corrosive-erosive wear tests were carried out by corrosive-erosive wear tester (Fig. 3.1). Three specimens are tested at a time for constant conditions.



Fig. 3.1 Corrosive-erosive test rig

Three specimens of 20mm diameter and 20mm length with smooth finish are placed at 120° apart circumferentially at 0.1 m radius, to maintain dynamic balance. The specimen holder was rotated at 1440 rpm using electric motor for maintaining sample speed of 5 m/s. The experiment was repeated three times for each set of identical test conditions. 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 0.1-100 km. The composition alumina particle was (90-150 nm) from 0 to 30- wt% (interval of 10-wt.%) in the H2SO4 liquid concentrations of 0.01, 0.1 and 1.0 N. Weight loss was determined by weighing the specimen before and after the tests. Though the corrosion-erosion wear was measured as the weight loss, the wear rate was calculated by the following formula.

$$V_{ce} = \frac{\Delta W}{\rho A t}$$

Where V_{ce} is corrosive-erosive wear rate ($\text{cm}^3\text{m}^{-2}\text{h}^{-1}$),

ΔW is weight loss (g),

ρ is specimen density (gcm^{-3}),

A is the eroded area (m^2) and

t is the testing time (hr).

The uncertainty level of the experiment is ± 2.36 mg.

4. RESULTS (Corrosive erosive properties)

Table: 4.1 Shows V_{ce} ($\text{cm}^3/\text{m}^2 \text{ h}$) of Al/nanoclay MMCs in Tap water

Sliding distance, km	% of nanoclay				
	0	5	10	15	20
0.1	0.0000	0.0000	0.0000	0.0000	0.0000
0.5	0.0630	0.0540	0.0520	0.0500	0.0445
1	0.0460	0.0390	0.0380	0.0360	0.0320
5	0.0270	0.0230	0.0220	0.0210	0.0185
10	0.0120	0.0100	0.0100	0.0096	0.0086
50	0.0100	0.0080	0.0080	0.0080	0.0070
100	0.0090	0.0070	0.0070	0.0070	0.0060

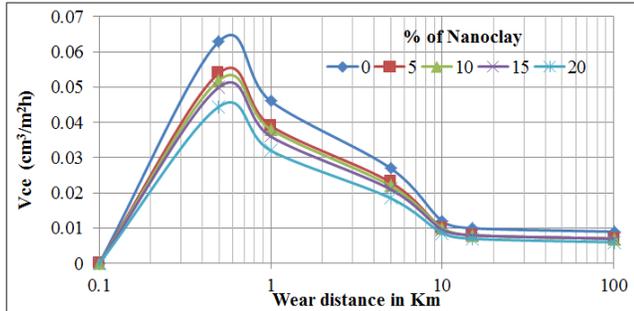


Fig. 4.1 Vce rate vs. wear distance of Al/nanoclay composites in the tap water

Table 4.2 Shows Vce (cm³/m² h) of Al/Nanoclay MMCs in 1N H₂SO₄ + 30% alumina

Sliding distance, km	% of nanoclay				
	0	5	10	15	20
0.1	0	0	0	0	0
0.5	12.0500	8.3690	8.1236	8.0265	6.0633
1	8.9000	7.6487	7.4388	7.3536	6.623
5	6.4000	5.5002	5.3492	5.2400	4.7146
10	7.6600	5.2337	4.8265	4.6800	3.2633
50	9.4700	5.0260	4.3295	4.2800	1.7098
100	9.8800	4.9350	4.2794	4.2200	1.4197

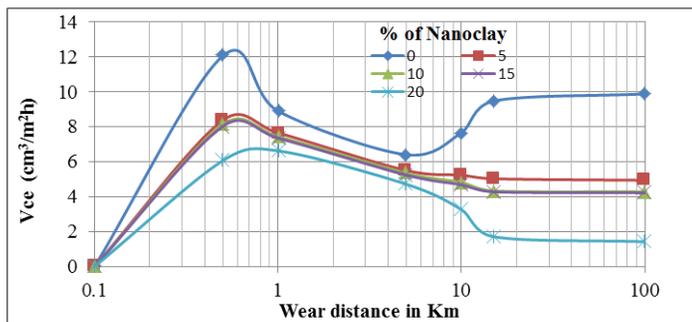


Fig.4.2 Vce rate vs. wear distance of Al/nanoclay composites in the 1N H₂SO₄ + 30 % alumina particulate

Figure 4.1 (Table 4.1) and Fig. 4.2 (Table 4.2) shows the variation in Vce of Al /nanoclay composite with wear distance in tap water and 1N H₂SO₄ + 30% Al₂O₃ particles. In the Fig. 4.2, the Vce values of both the matrix and the composites in tap water have very low values compared to those under slurry conditions. Vce curves of both the matrix and the composites show similar trends and increase initially with distance, attain a peak, decrease thereafter and finally attain a steady-state value at a longer distance. Aluminum is a very reactive metal but forms a protective oxide film when exposed to air, the stability of which is much greater than the metal itself. This protective oxide film provides protection from general corrosion in neutral solutions. But the protective oxide film includes cracks or fissures on its surface. The film chips as small flakes when the specimens pass through water at a high speed resulting in spalling effect. Hence, Vce is high at the initial stage and then decreases and reaches a steady state [11].

In all the cases, the composites experienced a reduced Vce than the matrix alloy. In the composite, the wear rate decreases more or less monotonically with the sliding distance. However, in matrix alloy, the wear rate initially increased to a peak value and then decreased with the sliding distance only up to 7.5 km before increasing again, Fig.4.2. This could be interpreted in terms of the effects of both the abrasive particles and the corrosive media on the corrosive-erosive wear.

Table 4.3 Vce (cm³/m² h) variation of Al/Nanoclay MMCs in Slurry of 0N H₂SO₄ with Various wt % alumina particulate at distance of 100 km

Wt % Alumina particulate	% of nanoclay				
	0	5	10	15	20
0	0.009	0.007	0.007	0.007	0.006
10	1.24	0.91	0.82	0.57	0.36
20	2	1.7	1.6	1.32	1.12
30	2.44	2.12	1.96	1.66	1.42

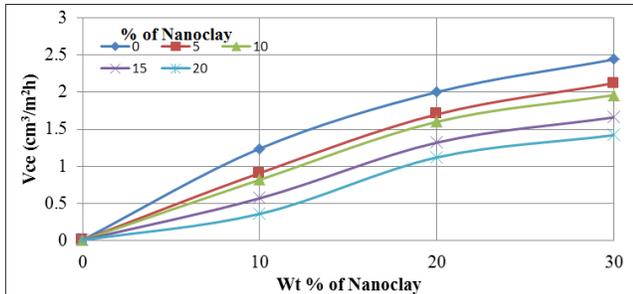


Fig.4.3 Vce vs. amount of alumina in slurry for both Al 6061 matrix alloy a Al6061/ nanoclay composites

Table 4.4 Vce (cm³/m² h) variations of Al/Nanoclay MMCs in Slurry of 1 N H₂SO₄ with various wt% alumina particulate at distance of 100 km

Wt % Alumina particulate	% of nanoclay				
	0	5	10	15	20
0	1.83	1.586	1.3	1.22	0.96
10	4.46	2.51	2.19	2.02	0.89
20	7.09	3.58	3.37	2.98	1.12
30	9.88	4.935	4.279	4.22	1.42

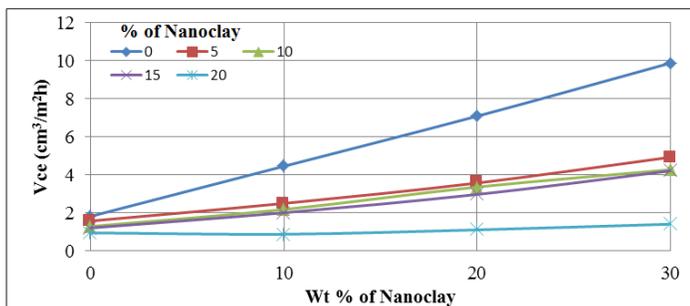


Fig. 4.4 Vce vs amount of alumina in slurry for both Al 6061 matrix alloy and Al6061/ nanoclay composites

Table 4.5 Vce (cm³/m² h) variations of Al/Nanoclay MMCs in Slurry of without alumina particulate with various N of H₂SO₄ at distance of 100 km

Normality of H ₂ SO ₄	% of nanoclay				
	0	5	10	15	20
0.001	0.009	0.007	0.007	0.007	0.007
0.01	0.57	0.35	0.19	0.11	0.11
0.1	1.24	0.91	0.7	0.54	0.54
1	1.83	1.586	1.3	1.22	1.22

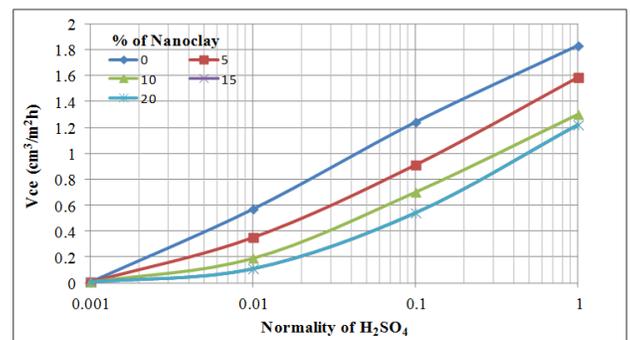


Fig. 4.5 Vce vs. concentration of H₂SO₄ slurry for both Al 6061 matrix alloy and Al6061/ nanoclay composites (without abrasive)

Table 4.6 Vce (cm³/m² h) variation of Al/Nanoclay MMCs in Slurry of with 30 % Alumina particulate with various N of H₂SO₄ at distance of 100 km

Normality of H ₂ SO ₄	% of nanoclay				
	0	5	10	15	20
0.001	2.44	2.12	1.96	1.66	1.66
0.01	2.99	2.25	2.05	1.95	1.95
0.1	4.95	3.48	3.02	2.6	2.60
1	9.88	4.935	4.2793	4.22	4.22

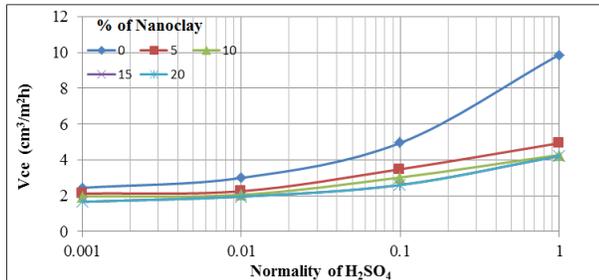


Fig. 4.6 Vce vs. concentration of H₂SO₄ slurry for both Al 6061 matrix alloy and Al6061/Nanoclay composites (with 30% alumina particulate)

Figures. 4.3, 4.4, 4.5 and 4.6 shows that the wear rate of each material increases with the concentration of H₂SO₄, as expected. In fact, the corrosion attack has a stronger tendency to penetrate more deeply as the concentration of the H₂SO₄ solution increased from 0.01 to 1 N. The corrosive- erosive wear rate of the composites greatly decreased due to the reinforcing particles preventing the intrusion of the erodent and blocking the propagation of micro-cracks. The same trends were observed for different concentrations of H₂SO₄ environment.

During slurry wear testing, the sample rotating in the slurry suffer from surface damage in three ways, namely, purely corrosive attack from the corrosion medium, purely erosive attack from the abrasive particles and the corrosive-erosive combined attack. The corrosive-erosive wear rate of the experimental condition is higher than the sum of corrosion rate by H₂SO₄ of the same concentration and erosive rate by Al₂O₃ particles of the same wt. %. On one hand, after the surface is cut off, ploughed or impacted in the erosion process, a certain volume of the material is left undeformed. Erosion causes exposure of greater areas of base metal to the corrosive media. Greater the area of exposure greater is the corrosion.

On the other hand, after corrosion the surface of the material becomes porous, it becomes weaker and is followed by cutting, ploughing or impact of the suspended particles will be easier and more effective, thus, corrosion accelerates erosion. The above observations lead to the conclusion that the effect of combined erosion-corrosion and abrasion by the slurry flow is responsible for the higher loss of specimen material, and the action of abrasion damages the passive film on the surface of the material,

which accelerates the corrosion. Moreover, the corrosion attack further aids the abrasion process.

The wear rates of both Al and Al composites significantly increase with the increasing volume fraction of the alumina particles. But the nature of curve changes for pure corrosive and erosive wear. The presence of the solid suspended particles in the medium increases the extent and rate of overall material loss of the samples.

5. CONCLUSIONS

- The composites attained better corrosive-erosive (Vce) wear resistance than the matrix alloy irrespective of the test condition
- The erosive-corrosive wear rate of the specimen have an exponential relation with the H₂SO₄ concentration and erosion speed of the slurry
- Corrosive wear was the predominant mechanism of material removal in the corrosion and abrasion modes of wear.

REFERENCE

- [1] Xu H, Palmiere EJ. Particulate fracture during the thermo mechanical processing of a SiCp/Al metal matrix composite. Mater Sci Forum 1996; 217–222(2):1091–6.
- [2] Vedani M, Pozzi M, Tuissi A. Microstructural and damage behaviour of Al-6061/Al₂O₃P composites during hot and cold rolling. In: Proceedings of the international conference Euromat 2001. Rimini: AIM publisher; 2001. p. 411.
- [3] Kim WJ, Lee YS, Moon SJ, Hong SH. High strain rate superplasticity in powder metallurgy aluminium alloy 6061 + 20 vol% SiCp composite with relatively large particle size. Mater Sci Technol 2000;16(6):675–80.
- [4] G.M. Zhao, Y.Q. Yang, W. Zhang, X. Luo, B. Huang, Y. Chen, Microstructure and grain growth of the matrix of SiCf/Ti–6Al–4V composites prepared by the consolidation of matrix-coated fibers in the β phase field Composites Part B: Engineering, Volume 52, September 2013, Pages 155-163

- [5] Sahin Y. The mechanical and wear behaviour of metal matrix composites. Ph.D. Thesis. UK: Aston University in Birmingham, 1994.
- [6] Alpas AT, Zhang J. Wear transition in cast aluminium-silicon alloys reinforced with SiC particles. *Scr Met Mater* 1992;26:505 –509
- [7] Akbulut H, Durman M, Yilmaz F. Dry wear and friction properties of d-Al₂O₃ short fibre -reinforced Al-Si alloy. *Wear* 1998;215:170 –176.
- [8] B.Q. Han, K.C. Chan, “Superplastic deformation mechanisms of particulate reinforced aluminium alloy matrix composites”, *Materials Science and Engineering*, A212, 1996, pp.256-264.
- [9] Vedani M, Gariboldi E. Hot forming related properties of Al6061/Al₂O₃ and Al 2618/Al₂O₃ composites. In: *Proceedings of the international Conference Limat 2001*, Centre for Advanced Aerospace Materials, Pohang University of Science and Technology, Pusan; 2001. pp. 375–80.
- [10] Prasad YVRK, Sasidhara S. Hot working guide – a compendium of processing maps. ASM International Publisher; 1997.
- [11] Vedani M, Pozzi M, Tuissi A. Microstructural and damage behaviour of Al-6061/Al₂O₃P composites during hot and cold rolling. In: *Proceedings of the international conference Euromat 2001*. Rimini: AIM publisher; 2001. p. 411.