



## Corrosion Studies of ZA-27/Red Mud Metal Matrix Composites in Sodium Chloride and Sodium Hydroxide Medium by Static Weight Loss Method

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### ABSTRACT

Weight loss corrosion studies of ZA-27/red mud metal matrix composites are studied in this research work. Metal matrix composites show improved corrosion resistance than metals and alloys. They find their application in automobile and air craft industries. ZA-27 is a commercially available alloy. Red mud is a waste obtained after the removal of ZA-27 from its ore. ZA-27 is reinforced with 2, 4, and 6 weight percentage of red mud particulates by liquid melt metallurgy technique using vortex method. Machined specimen was subjected to microstructural studies. Weight loss corrosion tests were carried out according to ASTM standards G-69 in sodium chloride and sodium hydroxide mediums. Tests were conducted up to 96 h with 24 h interval. Corrosion rate was found to be decreased with increase in exposure time in both mediums. Effect of exposure time and presence of increased percentage of reinforcement red mud is discussed in detail.

**Key words:** Red mud, Vortex, Composites, Corrosion

### 1. INTRODUCTION

Metal matrix composites are engineering combination of two or more materials (one of which will be metal or alloy) where tailored properties are achieved by systematic combination of different constituents. Composites are metal systems consisting of a mixture of two or more constituents' insoluble in each other and differing in form and material composition. They are heterogeneous materials consisting of two or more phase, which are in intimate contact with each other on a microscopic scale. They are also homogeneous material in sense that any part of it will have the same physical properties on a microscopic scale. The present research work involves the above-mentioned metal matrix composites where ZA-27 is reinforced with red mud particles and their corrosion characterization in equimolar solutions of sodium chloride and sodium hydroxide [1-11].

### 2. EXPERIMENTAL PROCEDURE

#### 2.1. Material Selection

The matrix selected is ZA-27 alloy which is commercially available. Its composition is given in Table 1.

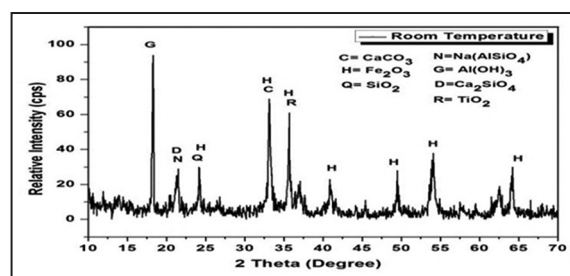
Red mud was selected as reinforcement material due to its good hardness properties, easy availability, and

low cost. It is a waste obtained after the removal of aluminium from its ore. It is procured from HINDALCO, Renikoot district, Uttar Pradesh state, India. Red mud was subjected to X-ray powder diffraction (XRD) analysis to know the composition.

Figure 1 shows the XRD analysis of red mud particulates. The main components found in the XRD analysis are hematite ( $\text{Fe}_2\text{O}_3$ ), gibbsite ( $\text{Al}(\text{OH})_3$ ),

**Table 1:** Composition of ZA-27.

Aluminium	Copper	Magnesium	Zinc
26-28%	2-2.5%	0.01-0.02%	Balance



**Figure 1:** X-ray powder diffraction analysis of red mud.

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rutile ( $\text{TiO}_2$ ), calcite ( $\text{CaCO}_3$ ), sodium aluminium silicate ( $\text{NaAlSiO}_4$ ), dicalcium silicate ( $\text{Ca}_2\text{SiO}_4$ ), and quartz ( $\text{SiO}_2$ ). [21] [12].

Corrosion medium used was equimolar solutions of sodium chloride and sodium hydroxide of 0.25M, 0.5M, and 1 M concentrations.

## 2.2. Preparation of the Composite

This ZA-27-red mud metal matrix composites were prepared by liquid melt metallurgy technique using vortex method a method adopted by Kruipakara [13]. Red mud particulate size was selected was 50-80 microns based on the experience and reference to various technical reports. The weight of percentage of red mud particulates selected was 2-6% insteps of 2%. ZA-27 matrix is heated above  $600^\circ\text{C}$ , melt was degassed using nitrogen gas. Mechanical stirrer coated with aluminite (to prevent migration of ferrous ions from the stirrer material into the ZA-27 melt) is used to create the vortex. It is rotated at a speed of 400 rpm. Preheated but uncoated red mud particulates are added to the melt at a rate of 50 g per min. The molten metal was then poured into permanent molds for casting. Castings were produced in the form of cylindrical rods [diameter 30 mm and length 150 mm].

## 2.3. Specimen Preparation

The material was cut into  $20 \times 20$  mm pieces using an abrasive cutting wheel. The matrix alloy also cast under identical conditions for comparison. The samples were successively ground using 240, 320, 400, and 600 SiC paper and were polished according to standard metallographic techniques and dipped in acetone and dried. The samples were weighed up to fourth decimal place using electronic balance and also the specimen dimensions were noted down using Vernier gauze.

## 2.4. Scanning Electron Microscopy

Before the corrosion test the specimen of matrix and composites were subjected to microstructural studies using scanning electron microscopy.

Figures 2-5 show the microstructure of ZA-27 matrix alloy and its composites. In the Figures 3-5 even distribution of the reinforcement is visible.

## 2.5. Corrosion Test

The corrosion behavior of ZA-27-red mud MMCs was studied by immersion test. The static immersion corrosion method was adopted to measure the corrosion loss. Equimolar solutions of sodium chloride and sodium hydroxide of 0.25M, 0.5M, and 1 M concentrations were used as corrodent to characterize the corrosion behavior. 200 ml of the prepared corrodent solutions were taken in series of beaker. Samples were

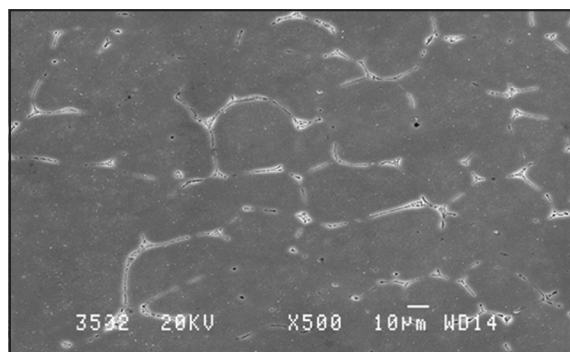


Figure 2: Microstructure of the matrix.

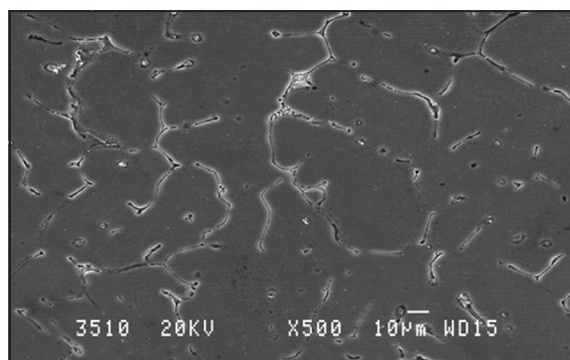


Figure 3: Microstructure of 2% composite.

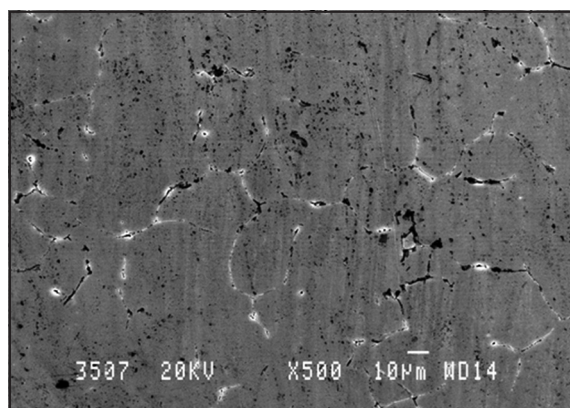


Figure 4: Microstructure of the 4% composite.

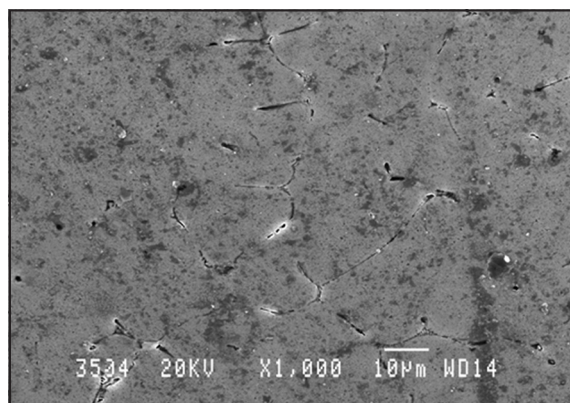


Figure 5: Microstructure of 6% composite.

suspended in the corrosive medium for different time intervals up to 96 h in the steps of 24 h. To minimize the contamination of the aqueous solution and loss due to evaporation, the beakers were covered with paraffin paper during the entire test period. After the specified time, the samples were cleaned mechanically using a brush to remove the heavy corrosion deposits on the surface. The corresponding changes in the weights were noted. Corrosion rates were computed using the equation.

Corrosion rate: =  $534 \text{ W/DAT mpy}$

Where W is the weight loss in g, D is density of the specimen in g/cc, A is the area of the specimen ( $\text{inch}^2$ ) and T is the exposure time in hours [14].

### 3. RESULTS AND DISCUSSION

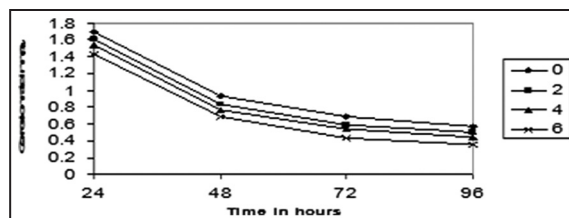
Figures 1-3 give the corrosion rate of composites with different percentage of red mud in different concentrated equimolar solutions of sodium chloride and sodium hydroxide.

#### 3.1. Effect of Test Duration

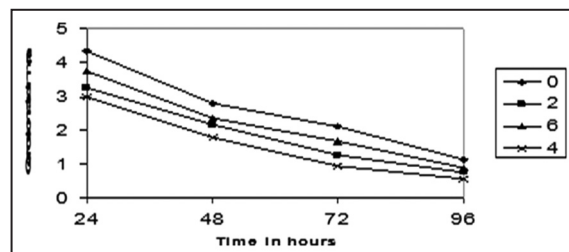
The corrosion rate mpy measurement as a function of exposure time in the static immersion test is shown in the Figures 6-8. The trend observed in both cases show decrease in corrosion with increase in test duration. It is clear from the graph that the resistance of the composite to corrosion increases as the exposure time increases. This eliminates the possibility of hydrogen bubbles clinging on to the surface of the specimen and forming a permanent layer affecting the corrosion process. The phenomenon of gradually decreasing corrosion rate indicates the possible passivation of the matrix alloy. De Salazar [15] explained that the protective black film consists of hydrogen hydroxy chloride, which retards the forward reaction. Castle *et al.* [16] pointed out that the black film consists of ZA-27 hydroxide compound. This layer protects further corrosion in acid media. However, exact chemical nature of such protective film still is not determined.

#### 3.2. Effect of Red Mud Content

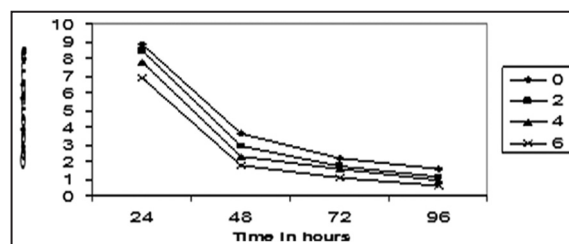
From the Figures 6-8 it can be clearly observed that for both as cast and composite, corrosion rate decreases monotonically with increase in red mud content. In the present case, the corrosion rate of the composites as well as the matrix alloy is predominantly due to the formation of pits and cracks on the surface. In the case of base alloy, the strength of the acid used induces crack formation on the surface, which eventually leads to the formation of pits, thereby causing the loss of material. The presence of cracks and pits on the base alloy surface was observed clearly. Since there is no reinforcement provided in any form the base alloy fails to provide any sort of resistance to the acidic medium. Hence, the weight loss in case of unreinforced alloy is higher than in the case of composites.



**Figure 6:** Weight loss corrosion in 0.25M equimolar solutions of NaCl and NaOH.



**Figure 7:** Weight loss corrosion in 0.5M equimolar solutions of NaCl and NaOH.



**Figure 8:** Weight loss corrosion in 1M equimolar solutions of NaCl and NaOH.

Red mud being the ceramic remains inert and is hardly affected by acidic medium during the test and is not expected to affect the corrosion mechanism of the composite. The corrosion result indicates an improvement in corrosion resistance as the percentage of red mud particulates increased in the composite, which shows that the red mud particulates directly or indirectly influence the corrosion property of the composites. Sathish *et al.* [17] who obtained similar results in glass short fiber reinforced ZA-27 alloy composites reported that the corrosion resistance increases with increase in reinforcement. Jinaxin *et al.* [18] in their work on corrosion of ZA-27 based particulate reinforced MMCs, state that the corrosion is not affected to a significant extent by the presence of red mud particulates in ZA-27, whereas the particulates definitely play a secondary role as a physical barrier as far as MMC corrosion characteristics are concerned. A particulate acts as a physical barrier to the initiation and development of corrosion pits and also modifies the microstructure of the matrix material and hence reduces the rate of corrosion.

One more reason for the decrease in corrosion rate is the intermetallic region, which is the site of corrosion



forming crevice around each particulates, which may be due to formation of magnesium intermetallic layer adjacent to the particulate during manufacture as discussed by Trzaskoma [19]. McIntyre *et al.* [20] further showed that the magnesium intermetallic compounds are more active than alloy matrix. Pitting in the composites is associated with the particulate matrix interface, because of the higher magnesium concentration in this region. With increase in time pitting would continue to occur at random sites on the particulate matrix interface. The active nature of the crevices would cathodically protect the remainder of the matrix and restrict pit formation and propagation.

#### 4. CONCLUSION

The red mud content in ZA-27 alloys plays a significant role in the corrosion resistance of the material. Increase in the percentage of red mud will be advantageous to reduce the density and increase in the strength of the alloy, but the corrosion resistance is thereby significantly reduced.

ZA-27 MMCs when reinforced with red mud of weight percentage from 0% to 7% could be successfully produced by liquid melt metallurgy technique.

The rate of corrosion of both alloy and composite decreased with increase in time duration in equimolar solutions of sodium chloride and sodium hydroxide. The corrosion rate of the composites was lower than that of the corresponding matrix alloy in hydrochloric acid and sodium chloride solutions.

#### 5. ACKNOWLEDGMENTS

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#### 6. REFERENCES

1. B. M. Girish, R. Kamath, B. M. Sathish, (1999) Fractography, fluidity and tensile properties of ZA-27/haematite particle composite, *Journal of Materials Engineering and Performance*, **8(3)**: 309-314.
2. B. M. Satish, K. H. W. Seah, B. M. Girish, (1996) Effect of short glass fibers on the mechanical properties of cast ZA-27 alloy composites, *Material and Design*, **17(5-6)**: 245-250.
3. P. Reynaud, (1996) Cyclic fatigue ceramic-matrix composites at ambient and elevated temperatures. *Composite Science and Technology*, **56**: 809-814.
4. S. C. Tjong, Z. Y. Ma, (1997) The high temperature creep behaviour of ZA-27 matrix composite reinforced with SiC, Al<sub>2</sub>O<sub>3</sub> and TiB<sub>2</sub> particulates, *Composite Science and Technology*, **57**: 697-702.
5. H. Akubulut, M. Durman, F. Yilnaaz, (1998) Higher temperature young's modulus of ZA-27 shore fire reinforced Al-Si MMCs produced by liquid infiltration, *Materials Science and Technology*, **14**: 299-305.
6. M. K. Aghajanian, G. C. Atland, P. baron-Antolin, A. S. Nagelberg, (1994) Fabrication and properties of metal matrix composites for automotive brake calipers applications. In: *Metal Matrix Composites*, Library of Congress Catalog Card Number 93-87522, Society of Automotive Engines, Inc. p77-81.
7. M.A.Dellis, J.P.Keusternas, F.Delannay, J.Wergia, (1991) Zn-Al matrix composites: Investigation of the thermal expansion, creep resistance and fracture, *Materials Science and Engineering: A*, **135**: 253-257.
8. S.H.J.Lo, S.Dionne, M.Sahoo, H.M.Hawthorne, (1992) Mechanical and tribological properties of zinc-aluminium metal-matrix composites, *Journal of Materials Science*, **27**: 5681-5691.
9. W. Smith, (1993) *Structures and Properties of Engineering Alloys*, 2<sup>nd</sup> ed. New York: McGraw-Hill, p567.
10. R. J. Barnhurst, K. C. Farge, (1986) In: Z. A. C. Alloys, G. P. Lewis, R. J. Barnhurst, C. A. Loong, (Ed.), *Proceedings of International Symposium on Zinc-ZA-27*, Toronto: CIM, p85.
11. N. Karni, G. B. Barkay, M. J. Barberger, (1994) The influence of manganese on the microstructure and the strength of a ZA-27 alloy, *Journal of Materials Science*, **13(17)**: 541-545.
12. H. Nath, A. Sahoo, (2014) A Study on the Characterization of Red Mud. *International Journal on Bioengineering*, **8(1)**: 1-4.
13. P. V. Krupakara, (2013) Corrosion characterization of Al6061/red mud metal matrix composites, *Portugaliae Electrochimica Acta*, **31(3)**: 157-164.
14. M. G. Fontana, (1987) *Corrosion Engineering*, New York: McGraw Hill Book Company Inc., p28-115.
15. J. M. G. de Salazar, A. Urefia, S. Mazanedo, M. Barrens, (1999) Corrosion behaviour of AA6061 and AA7075 reinforced with Al<sub>2</sub>O<sub>3</sub> particulates in aerated 3.5% chloride solution potentiodynamic measurements and microstructure evaluation, *Corrosion Science*, **41**: 529-545.
16. J. E. Castle, L. Sun, H. Yan, (1994) The use of scanning auger microscopy to locate cathodic centers in SiC/ZA-27 MMC and to determine the current density at which they operate, *Corrosion Science*, **36(6)**: 1093-1110.
17. B. M. Satish, (1997) Corrosion characteristics of ZA-27/glass-fiber composites, *Corrosion Science*, **39(12)**: 2143-2150.
18. J. Wu, W. Liu, P. Li and R. Wu, (1993) Effect of Matrix Alloying Elements on the Corrosion

- Resistance of SiC/Al Composites Materials, Journal of Materials Science Letters, 12: 1500-1501
19. P. P. Trazeskoma, (1990) Pit morphology of ZA-27 alloy and silicon carbide/ZA-27 alloy, *Corrosion Science*, **46(5)**: 402-409.
  20. J. F. Mclyntyre, R. K. Conrad, S. L. Go Hedge, (1990) Technical note: The effect of heat treatment on the pitting behaviour of SiC/AA2124, *Corrosion*, **46**: 902-907.

**\*Bibliographical Sketch**



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