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# ELECTROCHEMICAL STUDY OF AL 6061 COMPOSITES REINFORCED WITH HAEMATITE ORE PARTICULATES FOR CORROSION RESISTANCE

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## ABSTRACT

Since the 1990s, composite materials have received ansignificantimportance due to their exceptional corrosion and electrochemical properties,contributing to decreased waste, wear, tear, and corrosion, thus mitigating environmental risks.their superior mechanical characteristics, have created them highly desirable in factories like aviation. This study promotethe electrochemical attributes, especially corrosion resistance, of materials comprising Aluminium 6061 reinforced with haematite ore particulates. The fabrication process involved creating composite materials with varying weight percentages of haematite ore particulates (3%, 6%, and 9%) mixed with Aluminium 6061 using the LMM technique, specifically the vortex method. Additionally, pure Aluminium 6061 was cast using the same technique for comparison purposes or analysis. To assess the electrochemical behaviour, particularly corrosion resistance, satic weight loss corrosion tests and potential dynamic polarization tests were conducted using an electrochemical workstation. These tests were performed using three different concentrated solutions of sodium hydroxide. Scanning electron microstructures were examined before and after the satic weight loss corrosion tests to analyze any structural changes. The findings reveal that composite materials demonstrateimproved corrosion resistance with high reinforcement content. research pulled an valuable point into the electrochemical performance of Al6061 composites reinforced with haematite ore particulates, highlighting their potential applications in corrosion-resistant materials.

**KEYWORDS:** Aluminium 6061, Composite, Electrochemical, Polarization, Vortex, Weight loss

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## INTRODUCTION

Composite materials integral to modern engineering and manufacturing due to their unique heterogeneous structure. Which combines unique properties. Composites typically comprise a matrix material providingstructural bulk, enhancing specific characteristics. This blend allows composites to get a balance of strength, stiffness, and other properties that traditional materials might lack.

The matrix material in composites varies widely, including metals, alloys, polymers, or ceramics. eachcontributing distinct properties like ductility, toughness, or heat resistance. Reinforcements, such as Particles, fibers, or other forms, aim to improve specific performance aspects. For instance, particulate reinforcements can boost hardness and wear resistance, while fiber reinforcements enhance tensile strength and stiffness.

Metal matrix composites (MMCs), where the matrix is metal, often focus on enhancing mechanical properties and corrosion resistance. crucial in aerospace, automotive, and marine engineering.

Liquid melt metallurgy, a common method for MMC manufacturing,involves

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dispersing reinforcement materials into the molten metal matrix before solidification. The vortex method, a technique within this process, ensures effective mixing and distribution, yielding a uniform structure.

Research on MMCs has explored various reinforcement materials, including ceramics, metals, and minerals. Haematite, an iron oxide form, stands out due to its abundance, affordability, and favourable attributes like hardness and corrosion resistance.

Studies on haematite-reinforced aluminium alloys show promising results, indicating improvements in wear resistance, hardness, and corrosion resistance with higher haematite content. Nevertheless, further research is necessary to grasp potential applications fully and optimize composite materials.

In essence, composite materials, especially those like haematite-reinforced metal matrix composites, offer opportunities to enhance performance and meet diverse industry needs. Ongoing research and development in this realm will undoubtedly lead to further advancements in materials science and engineering.

## MATERIAL SELECTION AND METHODS:

Aluminium 6061 alloy, chosen as the matrix material for this investigation, is readily available commercially in the form of ingots or rectangular blocks. Prior to initiating the research, the alloy underwent compositional analysis to ascertain its precise composition. Presented below in table 1 is the composition of the aluminium 6061 alloy

**Table 1: Composition of aluminium 6061**

| Element | Mg | Si | Fe | CU | Ti | Pb | Zn | Mn | Sn | Ni | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Wt. % | 0.8-1.5 | 10-12 | 1 | 0.7-1.5 | 0.2 | 0.1 | 0.5 | 0.5 | 0.1 | 1.5 | Bal |

**Fig. 1: provided below depicts the aluminum 6061 alloy pieces used in the research.**

**Plate 1: 1: Aluminium 6061 alloy**

The figures and tables offer crucial insights into the composition and visual characteristics of the aluminium 6061 alloy, forming the basis for further analyses and discussions in the research. Thecompositional breakdown in the table meticulously details the weight percentages of different elements within the aluminium 6061 alloy.

This analysis is vital for understanding the alloys properties and behaviour in various applications, particularly when it serves as the fundamentalmatrix material in composite materials.

The chosen reinforcement material for this research is haematite ore particulates, characterizedby a size range of 50 to 80 microns. Haematite ore, readily available in Karnataka, India, wasselected due to its abundance and favourable properties. Sourced from the Kudremukh Iron Ore Company in Mangalore, India, this haematite ore is distinguished by its reddish-brown colorant this primarily composed of ferric oxide ($Fe_2O_3$) and silica ($SiO_2$). Renowned globally for itshaematite ore exports, this company offers a dependable supply or both research and industrial purposes

Haematite ore is a natural mineral comprised primarily of ferric oxide (Fe2O3) and silica (SiO2), resulting in its characteristic reddish-brown coloration. Figure 2 provided below illustrates the powdered form of haematite, showcasing its distinctive appearance.

**Plate 2: Haematite ore powder**

The process described involves fabricating composite materials by incorporating haematite ore particulates as reinforcements into an aluminium 6061 alloy matrix using the stir casting method, specifically utilizing the vortex technique. Here's a detailed explanation of each step: Preparation of Aluminium 6061 Alloy Matrix: Pieces of aluminium 6061 alloy is converted to molten state in a bottom pouring furnace. Introduction of Impeller and Generation of Vortex: An impeller, typically coated with aluminite to prevent contamination, is inserted into the molten alloy. It rotates at a controlled speed tocreate a vortex within the molten alloy, aiding in uniform dispersion of reinforcement particles.

**Degasification of Molten Alloy**: Nitrogen gas is introduced into the molten alloy to degasify it, removing any trapped gases or impurities that could compromise the final composite's quality. Preparation of Haematite Particulate Reinforcements: Haematite ore is sourced, sieved, and preheated to remove moisture content. The particles are then prepared within the desired size range. Addition of Haematite Particulates to the Vortex: The preheated haematite particulates are steadily introduced into the vortex at a controlled rate. This gradual addition ensures even dispersion within the molten alloy.

**Degassing and Removal of Entrapped Gas Bubbles**: Tablets of hexachloroethane may be added to aid in removing any remaining entrapped gas bubbles, ensuring minimal porosity in the final composite.Casting of Composite Material: Once the reinforcement particles are thoroughly mixed within the molten alloy, the composite mixture is poured into molds and allowed to solidify, forming cylindrical bar castings of specific dimensions. Post-Casting Treatment: The cast blend material may undergo various processing steps,such as heat treatment or machining, to further refine its properties and dimensions according to the specific requirements of the application. This process ensures the uniform dispersion and integration of haematite particulate reinforcements within the aluminium 6061 alloy resulting in composite materials withenhanced mechanical strength and corrosion resistance suitable for various industrial application

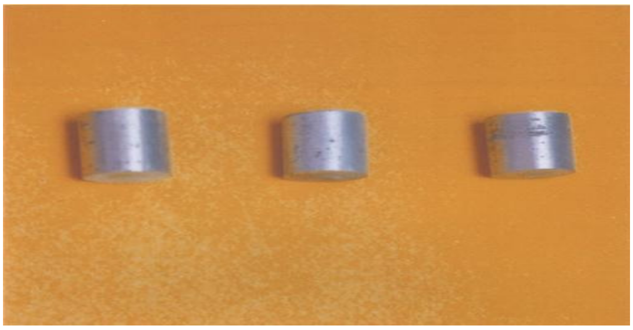
**Plate 3: Bottom pouring furnace**

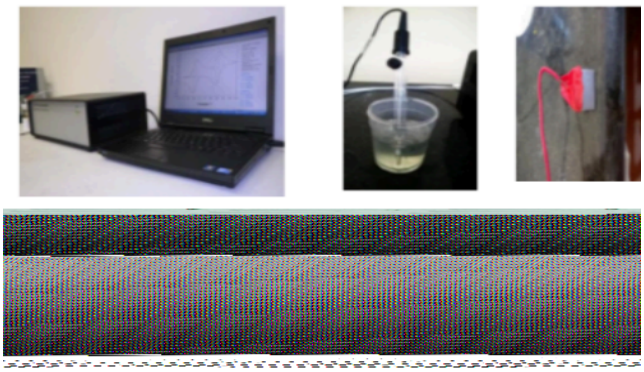
**Plate 4: Cylindrical bar castings of alloy and composites**

For the corrosion testing phase, specimens were prepared from cylindrical castings in strictwith ASTM G69-90 test standards to ensure precision and uniformity. Standardmetallographic techniques were employed to prepare the specimens, guaranteeing reliableresults. Rectangular specimens, sized 2 cm in length, 1 cm in breadth, and 1 mm in thickness, were prepared for potential dynamic polarization tests.

Prior to testing, the specimen surfaces underwent meticulous grinding using 1000-grit siliconcarbide paper to eliminate imperfections. Subsequent polishing steps, ranging from 1.5 to 3 μmdiamond, were performed to chieve a mirror-like surface finish, ensuring optimal conditions foraccurate testing. Each cylindrical specimen was weighed to the fourth decimal place for consistency and precision throughout the testing process. Plates 5 and 6 visually depict the meticulously prepared specimens used for electrochemical tests, emphasizing the attention to detail integral to this research.

**Plate 5: Specimen for weight loss test Plate 6: Specimen for polarization test**





The corrosion tests were carried out corrosion behaviour of the composite materials under varying levels of alkalinity. For the static weight loss test, specimens were immersed in sodium hydroxide solutions for up to 96 hours, with measurements taken every 24 hours to assess corrosion rates. The Fontana equation, Corrosion rate = 534W / DAT, was used to calculate corrosion rates in mils per year (mpy), considering factors such as weight loss, density, area, and exposure time.

Potential dynamic polarization tests were conducted using an electrochemical workstation model608E series by CH Instruments, USA. This equipment specializes in electrochemical measurements, including potential dynamic polarization tests, which provide insights into material corrosion behaviour under specific conditions. By recording the polarization curve while varying potential between electrodes and measuring resulting current, key parameters are determined, aiding in understanding corrosion mechanisms and kinetics.

Combining static weight loss tests and potential dynamic polarization tests offers a comprehensive evaluation of composite material corrosion resistance in sodium hydroxide solutions, providingcrucial data for potential applications in corrosive environments.

**Plate 7: Workstation**

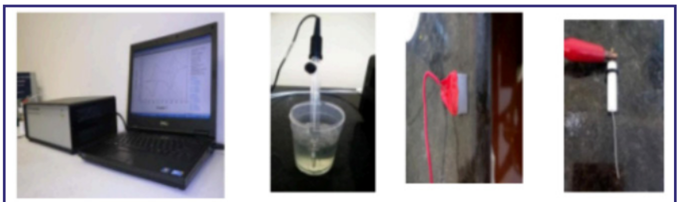


**Plate 8: Calomel Plate 9: Specimen Plate 10: Pt electrode**

The experimental setup included connecting the electrochemical workstation to a cell consisting of three key components: a reference electrode, WE (the sample), and anauxiliary or indicator electrode.Asaturated calomel electrode (SCE) served as the reference electrode due to its stable and welldefined reference potential, facilitating accurate potential difference measurement between the working electrode (sample) and the solution. The working electrode, representing the sample under examination, was securely placed in a holder within the cell. It was exposed to the test environment and monitored for potentialandcurrent changes throughout the experiment. An auxiliary or indicator electrode made of platinum completed the electrical circuit and facilitated current flow during electrochemical measurements. This setup provided precise control over electrochemical parameters like potential and current, enabling the generation of polarization curves and corrosion behaviour analysis. Visual representations of the saturated calomel electrode, the working electrode (sample), and the platinum electrode used in the polarization studies offered insights into the componentscomprising the experimental setup.

## RESULTS AND DISCUSSION

Plate 11to14 are the microstructures of Aluminium 6061 and its composites with different percentage of haematite ore particulates.

**Plate11:** SEM of Alloy

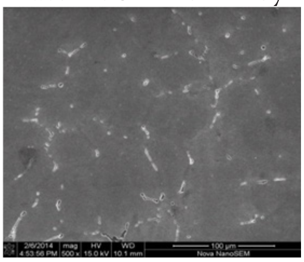
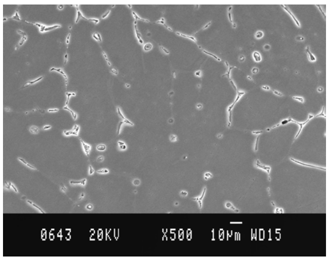


**Plate 12:** SEM of 3%



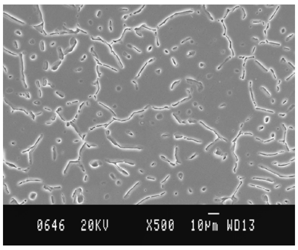




Plate **13:**SEM of 6%

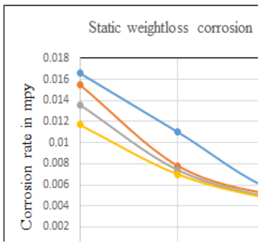



**Plate 14:** SEM of 9%

Figure 1 to 3 are the results obtained for the static weight loss corrosion tests in three different concentrations of sodium hydroxide solutions.

**Fig. 1: In 0.25 M NaOH**

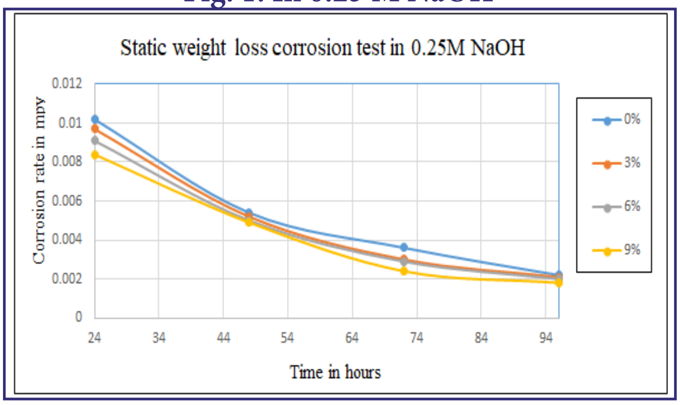



**Fig. 2: In 0.5 M NaOH**

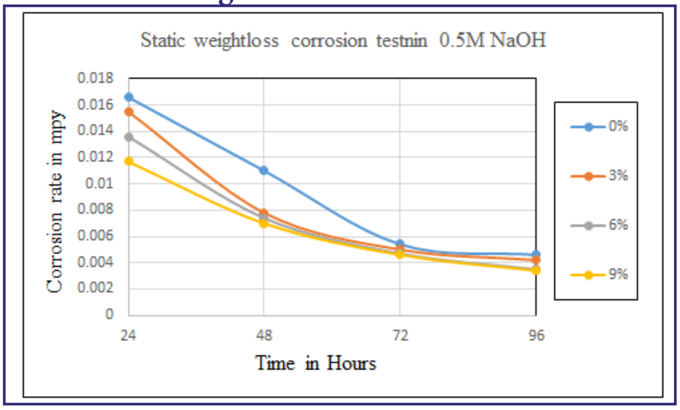
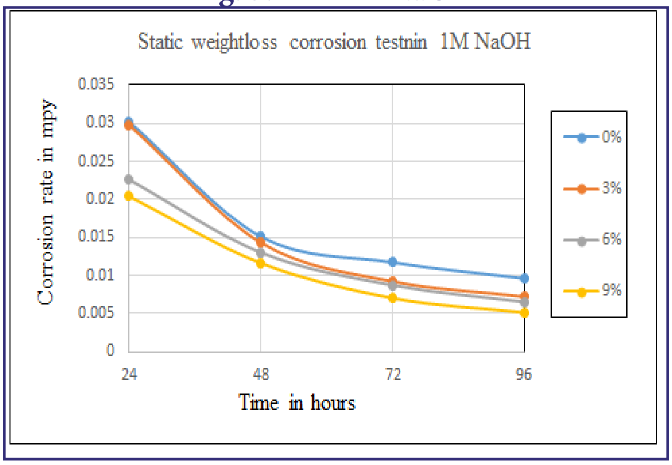



**Fig. 3: In 1 M NaOH**




During the weight loss test, the observed reduction in corrosion rates over time can be attributed to several factors. As the immersion time increases, there is a corresponding increase in the release of $Al^{3+}$ ions from the aluminium matrix. Furthermore, the increased generation of hydrogen gas, a byproduct of the cathodic reaction, aids in reducing corrosion rates. This gas can be trapped within surface crevices and cavities, acting as a physical barrier against further corrosion attacks.

As the concentration of Al3+ ions saturates in the solution, the anodic reaction responsible for aluminium dissolution slows down, leading to a decline in corrosion rates over time. This observation aligns with Trzaskoma's findings, where prolonged immersion in a saturated medium halts corrosion due to the absence of conducting species. Significantly, all tested samples demonstrate reduced corrosion rates with higher reinforcement content. This pattern stems from the inclusion of earthenware reinforcements, altering the corrosion behavior of composite materials. Compared to the pure matrix alloy, compositescontaining earthenware reinforcements exhibit lower corrosion rates. This can be attributed tothe reduced direct contact between the matrix alloy and corrosive media, resulting in decreased matrix alloy dissolution and enhanced corrosion resistance. In summary, the decrease in corrosion rates observed during the weight loss test over time isinfluenced by factors as the release of Al3+ ions, formation of protective oxide layers, trapping of hydrogen gas, and presence of reinforcement materials. These elements collectivelycontribute to the enhanced corrosion resistance of composite materials relative to the pure matrixalloy.

Figures 4 to 6 are the results of potential dynamic polarization studies of the composite materials in sodium hydroxide mediums which were obtained by employing electrochemical work station.

**Fig. 4: In 0.25M NaOH**

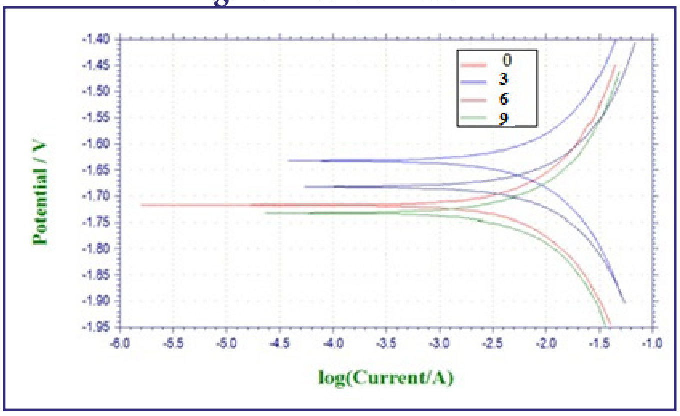



**Fig. 5: In 0.5M NaOH**

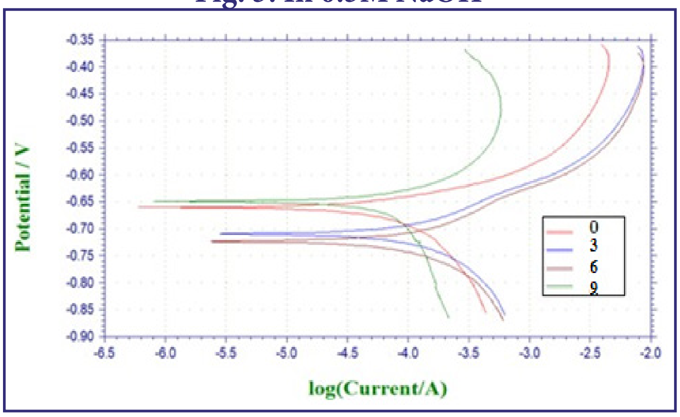
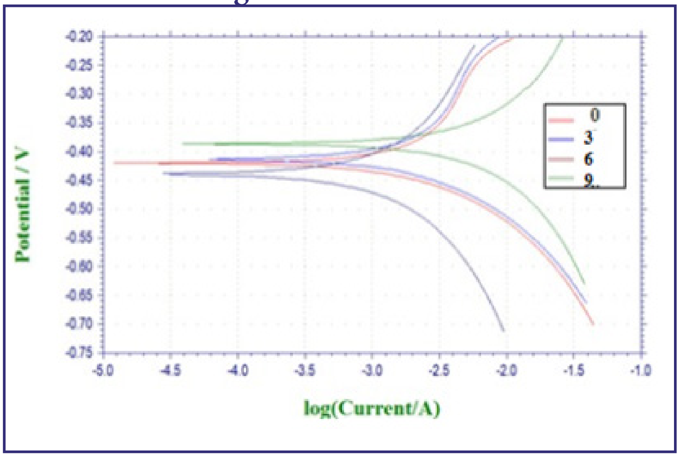



**Fig. 6: In 1M NaOH**




The results like corrosion rate in mpy obtained in the above graphs are tabulated in the table 2 given below.

| Percentage of Haematite | 0 | 3 | 6 | 9 |
|---|---|---|---|---|
| Concn.of NaOH | Corrosionrate inmpy | | | |
| 0.025N | 5.287 | 4.127 | 3.258 | 3.117 |
| 0.05N | 8.258 | 7.269 | 6.258 | 5.211 |
| 0.1N | 10.225 | 8.265 | 7.148 | 6.258 |

The tabulated results in Table 2 consistently demonstrate that higher concentrations of the corrosive medium lead to increased corrosion rates for both the alloy and composite materials. This correlation suggests intensified reactions between the samples and the medium, accelerating the corrosion process. Conversely, lower interaction of sample and the corrosive medium results in reduced corrosion rates. Upon analyzing the Tafel plots, similarities are observed in the anodic and cathodic curves for both the matrix alloy and composite materials. However, a slight shift in the cathodic curve towards the less negative side indicates a decrease in hydrogen gas liberation. This alteration suggests a modification in the electrochemical behaviour of the materials, potentially influencing their overall corrosion resistance properties.

In summary, these findings underscore the importance of considering corrosive medium concentration when evaluating the corrosion behaviour of alloy and composite materials. Additionally, the observed shifts in the Tafel plots gives important insights into corrosion processes mechanisms and present potential opportunities for enhancing material corrosion resistance. Plates 15 to 18 are the microstructures of the matrix alloy Aluminium 6061 and its composite material reinforced with haematite particulates.

**Plate 15** : Alloy **Plate 16:**3 %

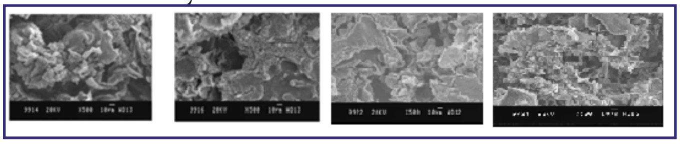


**Plate** 17:6% **Plate 18:** 9%

The examination of corroded surface morphology following polarization studies conducted in between the matrix alloy and sodium hydroxide reveals significant differences compositematerials. The matrix alloy exhibits a higher prevalence of pits, cracks, and flakes compared to the composite materials. Notably, a noticeable reduction in these structural irregularities as the percentage of reinforcement increases. This observation suggests that the inclusion of reinforcement particles plays a pivotal role in mitigating the formation of surface defects such as pits, cracks, and flakes. The presence of reinforcement likely strengthens the matrix, providing added stability and resistance against corrosion-related features' initiation and propagation.

In summary, these findings underscore the positive impact of reinforcement on the corrosionresistance of composite materials. By reducing the occurrence of surface defects, composite materials demonstrate enhanced durability and longevity in corrosive environments compared tothe matrix alloy alone. This highlights the significance of reinforcement in enhancing materialperformance under harsh conditions.

## CONCLUSIONS

In summary, this study centered on the fabrication varying proportions of haematite particulates using the liquid melt metallurgy technique via the vortex method. Subsequently, specimens underwent both static weight loss corrosion tests and potential dynamic polarization tests in solutions with different concentrations ofNaOH. The results consistently reveal an inverse relationship between the percentage of reinforcement and the corrosion rate across all sodium hydroxide concentrations. Specifically, as the proportion of haematite reinforcement increases, the corrosion rate decreases. This highlights the superior corrosion resistance properties of the composite materials compared to the matrix alloy alone.

These findings imply that composite materials, fortified with haematite particulates, offer heightened suitability for diverse applications compared to the unalloyed matrix. The integration of reinforcement particles effectively counteracts corrosion, thereby enhancing the complete durability of the materials in corrosive environments. In conclusion, these outcomes underscore the potential of composite materials as a practical solution for applications requiring exceptional corrosion resistance, presenting promising prospects for their adoption across various industrial sectors.

## REFERENCES

1. Om Prakash Sharma, AnojMeena, Study of mechanical properties and wear behaviour of aluminum 6061 matrix composites reinforced with Hematite and Titania, Materials Today: Proceedings, 44 (6), 2021, 5028-5036,.
2. R.L. Deuis, C. Subramanian, J.M. Yellup, Dry sliding wear of aluminium composites—A review, Composites Science and Technology, 5(4),1997,415-435
3. R.S. Rana, Rajesh Purohit, V.K. Soni, S. Das, Characterization of Mechanical Properties and Microstructure of Aluminium Alloy-SiC Composites, Materials Today: Proceedings, 2(1), 2015, 1149-1156,
4. M.V. Phanibhushana, C.N. Chandrappa, H.B. Niranjan, Study of Wear Characteristics of Hematite Reinforced Aluminum Metal Matrix Composites, Materials Today: Proceedings, 4 (2), Part A, 2017, 3484-3493,
5. Sunil Kumar M. ,Sathisha N. BatluriTilak Chandra, Development and Characterization of Aluminum Alloy Reinforced with Hematite Particulate Composite for Automotive Application: A Review, Journal of Experimental & Applied Mechanics,10(2), 201 9, 7- 11
6. Mirzoev, D.I., Nazarov, K.M., Mirsaidzoda, I. et al. Aluminum Matrix Composites with Hematite and Cast Iron Fillers.Inorg.Mater. Appl. Res. 12, 2021, 1014–1020
7. Krupakara P. V., Corrosion characterisation studies of al 6061/red mud metal matrix composites, Thesis submitted to Bharathidasan University, Tiruchirappalli, For the award of the degree of Doctor of Philosophy in Chemistry, 2017
8. Dr Ravishankar, Dr P.V. Krupakara, Studies on the corrosion behaviour of aluminium 2014/ albite metal matrix composites, Journal of Emerging Technologies and Innovative Research, 8 (5), 2021, c48-c55
9. A.Tejaswini, Anusha M.M., Dr.P.V.Krupakara, Corrosion Characterization of Aluminium 7075 Alloy / Red Mud Composites in Mixture of Sodium Hydroxide and Sodium Chloride Medium, Studies in Indian Place Names (UGC Care Journal), 40(70), 2020, 3058-3062
10. Lakshmi R, Radha H.R., Krupakara P.V., Latha V. Potentiodynamic Polarization Studies of Aluminium 2024 / Flyash Metal Matrix Composites, Cikitusi Journal for Multidisciplinary Research, 6(1), 2019, 32-36

11. V.Latha, Dr.H.R.Radha, Dr.P.V.Krupakara, R.Lakshmi, Electrochemical studies of Aluminium 6061 / Titanium Diboride Metal matrix Composites, Journal of Applied Science and Computations, 5(11), 2018, 398-403
12. H.V.Jayaprakash, P.V.Krupakara, Corrosion Studies of ZA-27/Red Mud Metal Matrix Composites in Sodium Chloride and Sodium Hydroxide Medium by Static Weight Loss Method, Indian Journal of Advances in Chemical Science,5(4) (2017) 280-284
13. Abdul Jameel, Krupakara P V, Jayaprakash, H V, Veeraiah M K, Corrosion studies of Al6061/ Red mud Metal Matrix Composites. Electrochem. Soc. India, 60(2011)100-104