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Advanced Hybrid Reinforced Aluminium 5052 Composites: A Next-Generation Approach to Mechanical Performance Enhancement

Anil Kumara K V[1], Sathyanarayani S[1], Raveendra R S[1], Satish Kumar K B[2]

[1]Department of Chemistry, Sai Vidya Institute of Technology, Bengaluru-560064
[2]Department of Chemistry, Acharya Institute of Graduate Studies, Bengaluru-560107

Corresponding author: anilkumara.kv@saividya.ac.in

ABSTRACT

The current investigation examines the mechanical properties of hybrid composites composed of Aluminium 5052 with Al2O3 and MoS2 as reinforcements, including maximum tensile strength, hardness, compression strength, and percentage elongation, in addition to corrosion properties such as corrosion caused by static weight loss in sodium nitrate solution. The vortex method of liquid melt metallurgy is employed to create hybrid composites. Specimens are machined in accordance with ASTM guidelines. The distribution of reinforcements was examined by taking microstructures of the alloy and hybrid composites. As stated by the study's findings, hybrid composites have better mechanical qualities and corrosion resistance than matrix alloys.

KEYWORDS: Aluminium, Compression strength, Composites, Hardness, Ultimate tensile strength.

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INTRODUCTION

Novel materials replace traditional metals and alloys in contemporary uses in the automotive, marine, aerospace, and military industries[1]. The urgent need for powerful resources is the main factor driving the popularity of this design. Regardless of the situation, lightweight materials are currently receiving more attention. Finding high-performance materials in a methodical manner with high strength-to-weight ratios has been the focus of recent advancements in these fields. Composites are the name given to these high-performance materials that are presently being created by different researchers. For the past 20 years, metal matrix composites have been widely used in high-performance applications. Since 2007, the utilisation of metal matrix composites is expected to grow at a pace of 8% annually. Because of its remarkable mix of mechanical and corrosion qualities, aluminium, Among the most prevalent materials on Earth, is most frequently employed as a metallic matrix material. [2-3]. The 5XXX series aluminium alloys' low density, high specific strength, strong corrosion resistance, and ease of production make them popular in the automotive, aerospace, and shipping industries.[4–7].
Among the most prevalent and widely used aluminium alloys in the 5XXX family is 5052, which only contains magnesium as a reinforcing element. Its application space is severely limited by its propensity to shatter under plastic deformation [8–9].

Singh Vijay Pratap et al. (2010) used an immersion test to investigate the cumulative roll bonding behaviour of aluminium 5052 alloy in relation to corrosion in various acidic, alkaline, neutral, and saline media. They found that this method might reduce weight loss by up to 74%. According to the literature review, there are very few corrosion investigations of aluminium 5052 hybrid composites. The mechanical and microstructural behaviour of aluminium 5052 composites with different percentages of silicon nitride particles was investigated by M. Gopinath and N. Senthil Kumar[10-11]. The authors examined the microstructure, roughness and strength to withstand tension and impact the composite's strength.

materials after they were prepared utilising the stir casting technique, and the sample was machined. They then compared the findings with those of a cast alloy. They claim that adding silicon nitride increases tensile strength, hardness, and impact strength while also improving strength and grain reinforcement. After producing aluminium 5052-SiC composites via liquid melt metallurgy, M. Kalyan Kumar et al. (2012) investigated their mechanical behaviour. Hardness, surface toughness, and microstructure evaluation tests were performed on varying percentages of preheated silicon carbide particles up to 10 weight percent. They claim that the composite materials showed a noticeable dispersion of reinforcement. When compared to matrix alloy, hardness values were also high with 10 weight percent SiC in the alloy. The mechanical characteristics of aluminium 5052 alloy augmented with boron nitride and silicon carbide hybrid composites made by stir casting were assessed by M. Mallesh et al. in 2013. They state that as the amount of reinforcement increased, so did the ultimate tensile strength, hardness, and impact strength. The mechanical behaviour of aluminium 5052 composite materials incorporating Al_2O_3 and MoS_2 has been researched thus far, according to a very extensive review of the literature. Thus, this research has been undertaken[12-13].

MATERIALS AND METHODS

Al 5052, a widely accessible aluminium alloy, was chosen for this study. Table 1 below shows its composition.

Table 1: Aluminium 5052's composition

Element	Mg	Cr	Cu	Fe	Mn	Si	Zn	Al
Percentage	2.2-2.8	0.15-0.35	0.1	0.4	0.1	0.25	0.1	Bal

The reinforcements used in this work are Al_2O_3 and MoS_2. These ceramic materials also available commercially. The composition of the above reinforcements is given in tables 2 and 3 respectively.

Table 2: Aluminium oxide's chemical makeup (Al_2O_3)

Elements	Ti	B	Fe	O	C	N
Wt.%	67.50	31.14	0.09	0.45	0.25	0.26

Table 3: Chemical composition of Molybdenum Sulphide (MoS_2)

Elements	Mo	S	Fe	Cu
Wt.%	59.94	40.05	0.005	0.001



Plates 1-3 show Aluminum 5052 alloy, Al_2O_3 and MoS_2 used in this work.

Plate 1: Al 5052 **Plate 2: Al_2O_3** **Plate 3: MoS_2**

The vortex method of liquid melt metallurgy is used to create hybrid composites. When molten Aluminium 5052 alloy was kept just above its melting temperature in a bottom pouring furnace, previously heated reinforcements were added. A mechanical impeller rotating at 400 rpm was inserted to create a vortex in the melt. Then, hexachloro ethane tablets are added to degasify the melt in order to release trapped gas bubbles. Cast iron moulds were used to create cylindrical bar castings. In order to compare the outcomes of the trials, Aluminium 5052 alloy was also cast in the same manner without reinforcements. This method was used to cast hybrid composites that contained two weight percent MoS_2 particles and two to six different weight percent Al_2O_3. Particles ranging from 50 to 80 µm were utilized to create hybrid composites. This work likewise follows the method used by Bheema Raju et al. (2014) for the production of hybrid composites. In accordance with ASTM guidelines, specimens were machined from the castings. The hybrid composites' microstructures were captured with a scanning electron microscope[13-14].

RESULTS AND DISCUSSION

Plates 4 to 7 given below display the microstructures of alloy matrix and hybrid composites. Uniform distribution of 2–6% of the weight of Al_2O_3.

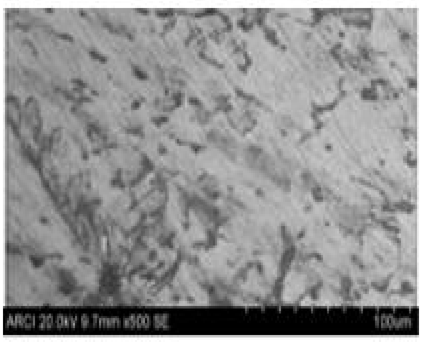

Plate 4: Microstructure of matrix aluminum 5052

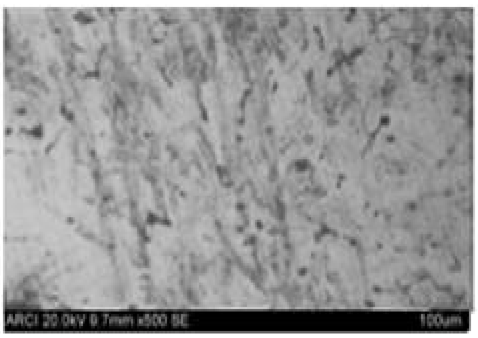

Plate 5: Microstructure of Aluminium 5052 with 2% MoS_2 and 2% Al_2O_3

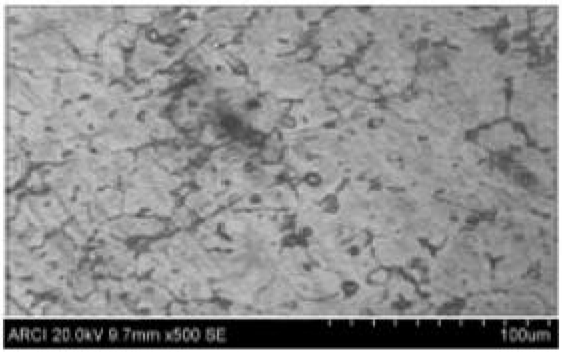

Plate 6: Microstructure of aluminium 5052 with 2% MoS_2 and 4% Al_2O_3

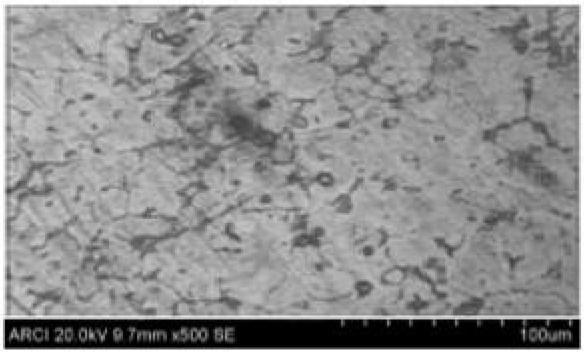

Plate 7: Microstructure of aluminium 5052 with 2% MoS_2 and 6% Al_2O_3

Figure 1 shows the values of ultimate tensile strength of the hybrid composites as opposed to matrix alloys. Figure 2 is the graphical representation of variation of percentage elongation of composites as opposed to matrix alloys.

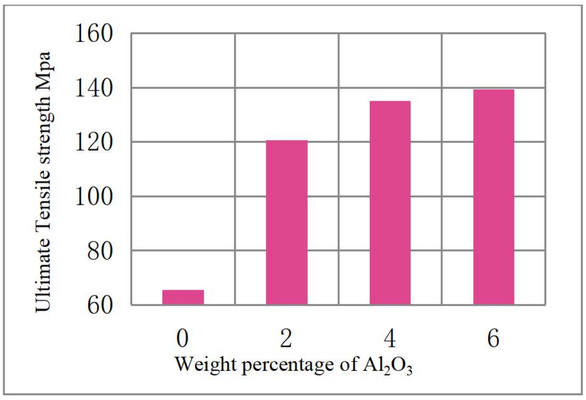

Figure 1: Values for ultimate tensile strength

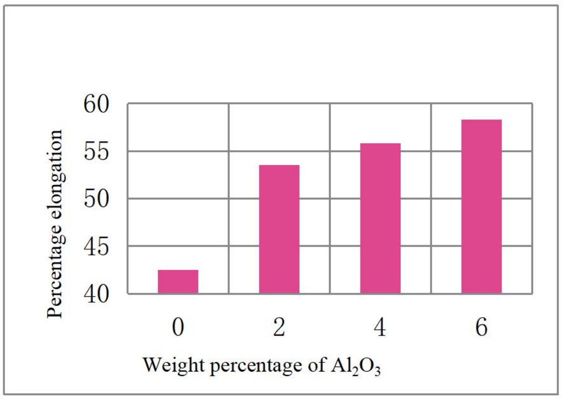

Figure 2: Percentage elongation Values

The hybrid composite's maximum tensile strength and % elongation values rise in tandem with the proportion of second reinforcement Al_2O_3. For the aforementioned experiments, six samples of matrix alloy and each hybrid composite were examined; Next, the average value was calculated and the results were plotted again. For Aluminium 5052 composite materials with different percentages of silicon nitride reinforcement, M Gopinath and N Senthil Kumar[15] found comparable outcomes. In their study on the mechanical characteristics of Aluminium 5052 reinforced with SiC and Al_2O_3, Mohan V et al. (2016) present the same findings. It has been explained that since reinforced particles prevent matrix plastic deformation, hybrid The ultimate tensile strength values of composites are greater. than Aluminium 5052 matrix alloy. Figure 3 given below shows the Brinell hardness number studies of the hybrid composites compared with the matrix alloy[16]. Figure 4 shows the compression strength of the hybrid composites in comparison with Aluminium 5052 matrix alloy.

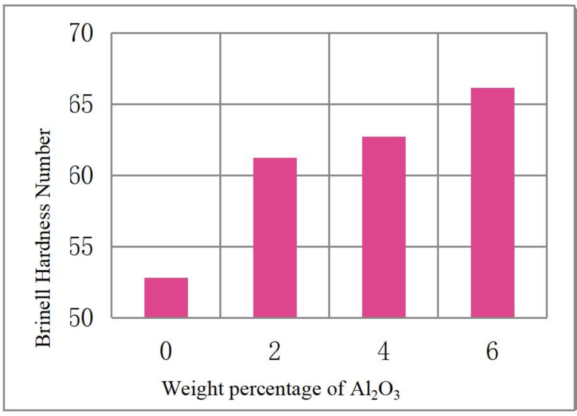

Figure 3: Brinell Hardness number

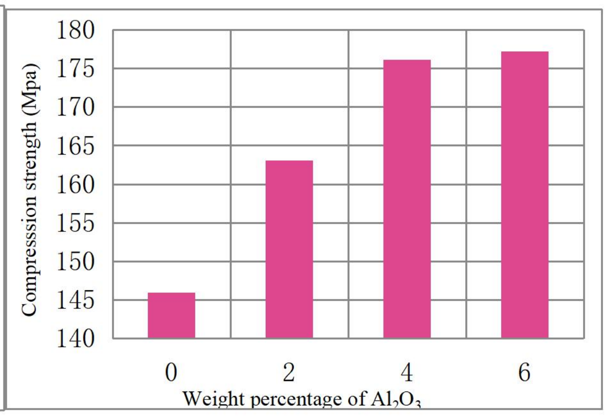

Figure 4: Compression strength in Mpa

In their studies on the hardness and compressive strength of composites constructed of Aluminium 5052 alloy with different percentages of silicon carbide particles, Murlidhar Patel et al. (2017) found comparable results. The material's capacity to withstand static stresses, abrasion, surface deformation, etc. is gauged by its resistance to indentation. results in the conclusion that there are intermolecular gaps and that adding red mud does not strengthen the interactions. This stands in stark contrast to the idea of interatomic bonding, where cohesiveness is significantly increased due to stronger interatomic forces. The intermolecular gaps must therefore be bridged. The substance is compressed to do this. The use of the compression strength thereby reduces the intermolecular gaps. In addition to this, casting flaws could be present in areas where voids, air bubbles, or blowholes are formed[17]. Applying a compressive load in these situations tends to compact the material much more closely. As a result, material will fill in these gaps. This tendency leads to a positive assessment that raising the proportion of Al_2O_3 will likewise boost the material's compression strength, which is a characteristic of cast iron and related materials.

The following are the findings of research on the hybrid composites rusting and static weight loss in odium nitrate solutions. The sodium nitrate solutions used for the testing were 0.035, 0.35, and 3.5 percent. Standard metallographic procedures were used to the test samples in accordance with ASTM G69-90 recommendations. They were machined into 20 mm long and 20 mm wide cylinders. Before testing, the surfaces of the samples were crushed. Using Silicon carbide paper with a granularity of 1000 and incrementally buffed with diamond paste of 1.5 to 3 µm to provide a mirror-like surface. Prior to being used to measure weight loss, the sample weights were recorded. Plate 8 below displays the specimens. 200 cm^3 of the corrosive media was used to submerge the samples. In accordance with the ASTM standard, 50 cm^3 of corrosive media divided by 1 mm^2 of sample exterior surface area was ensured. Throughout the entire test, the containers containing the corrosive media and sample were securely fastened with paraffin paper to prevent contamination and medium loss from evaporation. In stages of 24 hours, the immersion period was increased from 24 to 96 hours for each sample in order to perform the weight reduction erosion test. Plate 9 illustrates the container configuration.

Plate 8: Specimen for weight loss corrosion test

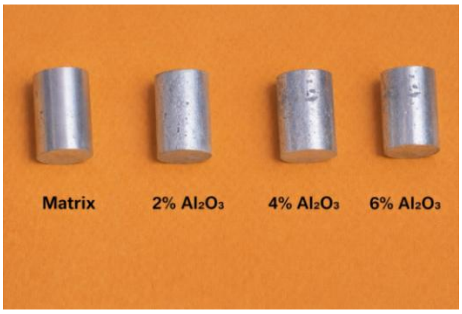

Plate 9: Containers arrangement

Figures 5 to 7 given below Display the computer models of the outcomes for corrosion tests using Aluminum's static weight reduction 5052 hybrid composites in three different concentrations on sodium nitrate solutions.

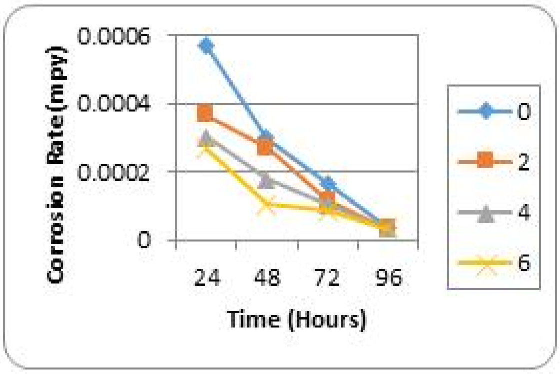

Figure 5: Weight loss in 0.035%$NaNO_3$

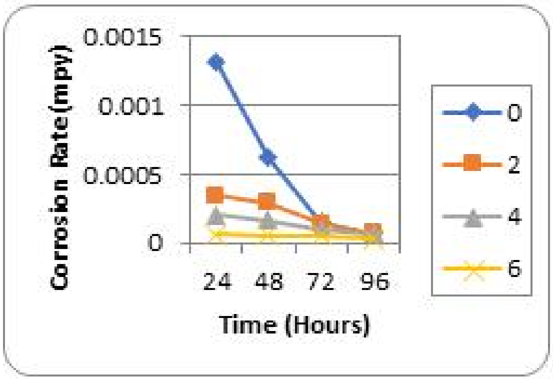

Figure 6: Weight loss in 0.35%$NaNO_3$

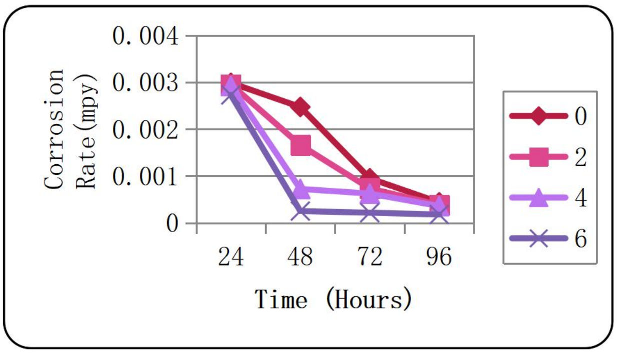

Figure 7: Weight loss in 3.5%$NaNO_3$

The aforementioned figures reflect how the erosion rates decreased throughout the tests. When the matrix alloy is passivated, the rate of corrosion is diminished. The whole surface of the sample is covered in a black layer of Aluminium hydroxide that is evident to the unaided eye. The matrix alloy and the surrounding corrosive media are kept apart by this passive layer. As a result, by keeping the sample from coming into direct contact with the medium, it lowers the rate of corrosion. According to Trzaskoma[18], samples submerged in a saturated liquid for an extended period of time will stop eroding since there are no conducting organisms. Compared to hybrid composite materials that contain earthenware, the matrix alloy corrodes more quickly. The matrix alloy corrodes more quickly than hybrid composite materials with earthenware reinforcements. This is due to direct interaction between the matrix alloy and the corrosive medium. The breakup of the framework amalgam increases since it shows little resistance to the actions of the surrounding media. Reinforcements added to matrix alloy create a link with the amalgam's surface to avoid direct contact with surrounding media. Because both reinforcements are ceramic, they are inert and cannot be harmed by corrosive agents. The results also demonstrate that corrosion resistance increases with increasing reinforcement content, indicating that the amount of reinforcement particles will influence the corrosion rate of the hybrid composite materials. Similar results were found by Kusuma et al. (2019) for Aluminium 356 hybrid composites reinforced with silicon carbide and fly ash. The corrosion rates of aluminum-based strengthened composite materials were significantly decreased by the addition of ceramic-based particles that acted as a physical barrier to the framework, according to Jianxin et al. After a static weight loss corrosion test, Plates 10–13 show matrix alloy and hybrid composite microstructures[19].

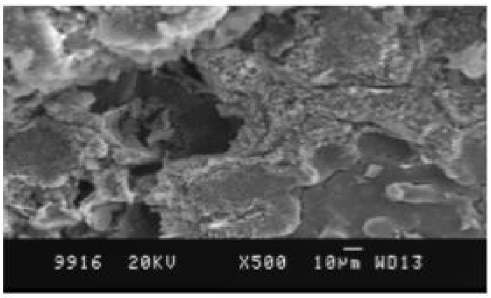

Plate 10: Matrix alloy

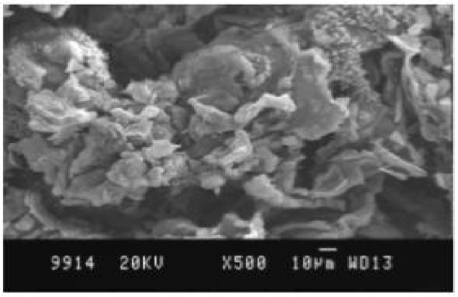

Plate 11: Hybrid composite 2% MoS_2 +2% Al_2O_3

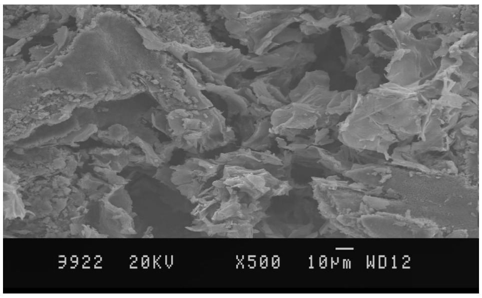

Plate 12: Hybrid composite 2% MoS_2+4% Al_2O_3

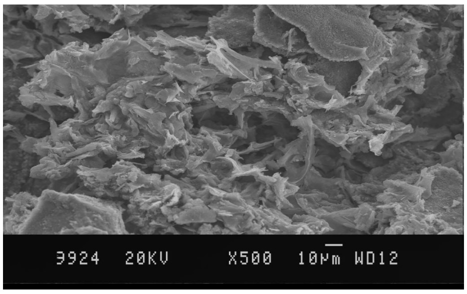

Plate 13: Hybrid composite 2% MoS_2 +6% Al_2O_3

It is evident from the aforementioned microstructures that the matrix alloy aluminium 5052 would experience significant corrosion, resulting in deep pits and fissures. Because it cannot provide resistance to corrosion media, there will be a significant reduction in weight. As the hybrid composites' alumina content rises, fewer flakes, pits, and fissures occur. In corrosion testing of Aluminium 6061 composites enhanced with red mud in various sodium chloride solution concentrations, found comparable results.[20]

CONCLUSION

In liquid melt metallurgy, the vortex method, also known as the stir casting process, is used to produce hybrid composites of Aluminium 5052 that include MoS_2 and Al_2O_3. The amount of MoS_2 stayed constant while the amount of Al_2O_3 varied. sample produced in compliance with ASTM standards. Microstructural examinations of the specimens using a scanning electron microscope showed a uniform distribution of reinforcements. Every mechanical attribute value grew as the amount of Al_2O_3 increased. Examinations of hybrid composites' static weight loss erosion in a range of concentrated sodium nitrate solutions reveal that the hybrid composites' corrosion rates were lower than those of the base amalgam. The corrosion rates of the hybrid composites decrease as the weight percentage of $Al_2O_3$and the immersion time rise. The lower rate of corrosion could probably be ascribed to microstructural changes in the framework.

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Conflict of Interests
The authors declare that there are no conflicts of interest.

Author Contributions

The current work is relevant to SDG-9: Industry, Innovation, and Infrastructure. All of the authors made major contributions to this paper, including reviewing and editing, and approved the final draft for publication. The writers' research profile can be verified using their ORCID ids, which are shown below: K. V. Anil Kumara https://orcid.org/0000-0003-2418-5145

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