Fabrication and characterization of sic, tio$_2$, and pksa hybrid aluminum-based metal matrix composites

Angadi Seshappa[1*], *Narasimhagari* Hiranmai[2], *Bhavanasi* Subbaratnam[3] *Konka* Prudhvi Raj[4], *Boya* Sravya[5], *Atul* Kumar Singla[6]

[1]Department of Mechanical Engineering, KG Reddy College of Engineering and Technology, Hyderabad, 501501, India.
[2]Department of Mechanical Engineering, G. Narayanamma Institute of Technology and Science For Women , Hyderabad, 500104,India.
[3]Department of Mechanical Engineering, Malla Reddy Engineering College and Management Sciences, Hyderabad-501401,India.
[4]Department of Mechanical Engineering, Mahatma Gandhi Institute of Technology (A),Hyderabad-500075, India
[5]Department of CSE, GRIET, Hyderabad, Telangana, India
[6]Lovely Professional University, Phagwara, Punjab, India.

Abstract. This study's 7075 aluminium uses the potential swirl moulding process, which incorporates silicon carbide, titanium dioxide, and PKSA additives. In this experimental investigation, the weight percentage of the smallest silicon carbide particle was kept constant at 3%. The titanium dioxide content ranged from 2% to 3%, whereas the weight percentage of PKSA was adjusted between 3% and 8%. The produced instances were subjected to a variety of tests, including a mechanical inspection, a microhardness examination, and an overall deterioration evaluation. The maximum tensile stress of this alloy is 8% more than that of the normal alloy. The increased elasticity of these augmented combinations was shown by the elasticity seen in a component. In addition, we saw substantial improvements in the longitudinal stiffness of its material. The microhardness of the solid waste products (PKSA) decreased, indicating their potential suitability for cost-effective reinforcement of a large amount of vehicle components. The degradation tests have been successfully done. There was a notable slowdown in the rate of decline. An extensive examination was performed using the Field Emission Scanning Electron Microscope (FESEM), which unveiled the spatial arrangement of components inside the aluminium composite.

1 Introduction

Alloys manufactured of aluminium have maintained a significant presence in the aerospace, automotive, and marine sectors due to their exceptional strength-to-weight ratio, which is

* Corresponding author: a.seshappa@kgr.ac.in

unsurpassed in the industry. The cheap cost of the material is mostly responsible for this consequence[1]. It was discovered that the porosity values of the 9% (SiC/Al_2O_3/PKSA) alloy that was reinforced with Al-7075 alloy were much lower (1.92%) than the porosity values of the Al-7075 alloy by itself (2.34%). The incorporation of amorphous silica resulted in an increase in microhardness (89%) and strength (with the incorporation of 9% hybrid nano-composite) as compared to the incorporation of a matrix and other nano-composites. The incorporation of amorphous silica into the composition was the cause of these phenomena. With the addition of nine percent AHNC, the tensile strength is higher than that of alloy by twenty-six percent, and the crash potency is also more advanced by twenty-two percent. The reason for this is because there is a significant amount of silica carbide (SiC) and TiO_2/PKSA present in the material[2]. Traditional aluminium alloys are being increasingly replaced by composites produced from metal matrix components. This is being done in order to bring about significant improvements in the physical properties of the composites. For the purpose of producing such compounds, it is necessary to include ceramic particles into a metal framework in order to lend strength to the structure. Through the incorporation of the qualities of ceramic granules, therefore [3], Particle manufacturing, hybrid moulding, and pressure moulding are among the several techniques used in the creation of mixes. The stir-cast process is often used because to its feasibility, cost-effectiveness, and ability to generate a substantial quantity of products. Currently, ongoing research focuses on hybrid composites, aiming to integrate the properties of many types of reinforcement into a metal matrix composite. Furthermore, to reduce expenses, synthetic reinforcing particles are progressively being substituted with agro-waste, therefore using the diverse range of accessible natural resources. This facilitates the industry's ongoing commitment to sustainability[4]. The manufacturing procedure of hybrid metal matrix composites included the use of silicon nitride and graphite particles. Increasing the quantity of ball-milled Si3N4+ graphite hybrid particle reinforcement resulted in an elevation in the material's hardness and tensile strength, while causing a decrease in its elongation[5, 6]. Equal parts of rice husk ash and TiC were blended in an AA-6061 metal matrix, yielding a composite material with enhanced properties, showcasing the synergy between these components[7An analysis of the mechanical properties of a hybrid metal matrix composite indicated a rise in characteristics such as ultimate tensile strength and microhardness by up to seven percent. However, once this limit was surpassed, reinforcing started to have an impact on both density and elongation. An investigation was conducted to study the mechanical properties of a hybrid reinforcement consisting of different weight percentages of rice husk ash (RHA) coupled with Al_2O_3. The study found that the hybrid reinforcement with a weight percentage of 10% was the most effective. The composites, which were strengthened with Al-Mg-Si alloy using a twofold stir casting technique, exhibited notably reduced porosity in comparison to Al_2O_3 alone. As the RHA % increased, the tensile strength and hardness decreased within the range of 3 to 4 weight percent. Graphite was then added to a mixture of RHA and Al_2O_3, which increased hardness by using the lubricating properties of graphite particles. This led to improved wear characteristics[8, 9]. The study focused on examining the tribological characteristics of hybrid composites made from precipitation-hardened 6061 aluminium alloy and granite dust. This includes conducting two-body sliding wear experiments, as well as evaluating the tensile strength and hardness of the composites. The research examined fluctuations in velocity and distance. The addition of 2 and 4 wt% granite dust and 2 wt% graphite resulted in a considerable enhancement in the mechanical properties and wear resistance of the base alloy. A hybrid metal matrix consisting of A6061 aluminium alloy, alumina, and graphite, was subjected to stirring with red mud reinforcement at 3, 7, and 11 wt%. This resulted in improved wear resistance and friction, with the highest increase seen at 11 wt%, reaching a peak enhancement of 48%. The SEM pictures demonstrated the occurrence of adhesiveabrasive wear when red mud was introduced[10]. An analysis was conducted on the mechanical properties of stir-cast AA-2024 alloy, which was strengthened with red mud and SiC microparticles. With the rise in red mud concentrations, there was a corresponding drop in both density and porosity. The increase in tensile strength was linked to red mud, according to variance analysis. The SEM scans detected both brittle and ductile failure mechanisms[11, 12]. The mechanical characteristics of AA356 matrix metal were evaluated using reinforcements of RHA (organic) and fly ash (inorganic) at different weight percentages (5%, 7%, 10%, and 12%). The addition of RHA and fly ash resulted in higher tensile strength and enhanced interface formation. The addition of 10 weight percent of rice husk ash (RHA) and fly ash increased the hardness. However, when the concentration of the additional reinforcements reached 12.5 wt%, the interfaces were degraded by the production of brittle reaction phases. This resulted in no advantages for the base metal. [13]. The technique of liquid metallurgy was used to enhance the strength of AA7075 by including 5 wt% of B4C and 3 or 5 wt% of RHA. The combinations consisting of 5% B4C and 5% RHA exhibited the maximum level of hardness. The statistical analysis demonstrated that the inclusion of B4C had the greatest influence on the enhanced tensile strength and hardness of the metal matrix composite [14]. The technique of liquid metallurgy was used to enhance the strength of AA7075 by including 5 wt% of B4C and 3 or 5 wt% of RHA. The combinations consisting of 5% B4C and 5% RHA exhibited the maximum level of hardness. The statistical analysis demonstrated that the inclusion of B4C had the greatest influence on the enhanced tensile strength and hardness of the metal matrix composite[15]. Investigated the performance differences between monocomposites of AA 6351 reinforced with RHA and SiC. With an increase in the RHA fraction, there was a corresponding drop in the composite density. This is in contrast to SiC-reinforced composites, where the reverse trend was found. Both kinds of composites exhibited enhanced mechanical and tribological properties [16].

There have been a great number of research investigations that have investigated the incorporation of agro-waste into aluminium composite alloys. These investigations have concentrated on the creation of mixed composite materials that include agro-waste as supplemental reinforcement. Several types of agricultural waste, including fly ash, rice husk ash, and red clay, have been the subject of research. On the other hand, we have not yet investigated the possibility of using byproducts from the process of oil extraction to produce biofuel. At the moment, researchers are investigating the possibility of using oily compounds derived from a variety of organic waste, such as naturally occurring kernels, as viable alternatives to conventional energy sources. Combustion of these substances results in the production of organic byproducts such as palm kernel shells, which are often dumped as waste ash, among other things. For the purpose of strengthening mixed aluminium matrix alloys, this research makes use of Palm Kernel Shell (PKS) and Oil Palm Kernel Shell (OPKS), two types of agricultural waste. The production of Highly Miniaturised Microchips (HMMC) was followed by the identification of ash that was obtained from palm kernel shells that had been burnt. Further components of the research included the analysis of microstructures and the deterioration of technological systems.

2 Content Designed Techniques

It was 7075 aluminium alloy that was used as the matrix for the reinforcing structure. All of the components that made up the reinforcing particles were leftovers of the manufacture of crude palm oil. These components were silica dioxide (SiO_2), titanium dioxide (TiO_2), palm kernel shell (PKS), and oil palm kernel shell (OPKS). The combination of the three reinforcing agents with acetone took place with the assistance of a magnetic stirrer, as shown in Table 1. Following the acquisition of the hybrid, it was dry and put to use. The

FTIR, EDS, and scanning electron microscopy techniques were used in order to characterise the palm kernel shell ash particles that are illustrated in Figure 1. The results of these techniques revealed that calcium carbonate was the main element. Sample fabrication was accomplished via the use of stir casting, which was selected because to its low cost and easy accessibility. The stir casting furnace was adjusted to a temperature of 780 degrees Celsius, which is the melting point of the aluminium alloy. After fifteen minutes of churning, the reinforcement was added, and the molten metal was whipped into a vortex to increase its strength. This process further strengthened the material[10]. After that, the material was inserted into a die that measured 100 millimetres by 100 millimetres by 6 millimetres. A cooling period of 10 hours was available.

Table 1: Casting of Hybrid Composites wt% and sample names

S.No	Al	PKSA	SiC	TiO2
1	85	5	5	5
2	85	8	5	3
3	85	7	5	4

To ensure that the cast composite samples were cut to the appropriate size for the tensile test, the ASTM E8M standard was used. In Figure 2, you can see examples of micro-hardness and wear test samples. On a DUCOM pin-on-disc machine, wear tests were carried out with the parameters set at a distance of 1500 metres, a velocity of 2.5 metres per second, and a weight of 2.5 kilonewtons. A universal tensile testing equipment was used in order to carry out the microhardness tensile testing as well. We carried out a number of FESEM tests on a CARL ZEISS (USA) MODEL: SIGMA WITH GEMINI COLUMN, with a resolution of 1.5 nm, in order to carry out an in-depth investigation of the dispersion of particles.

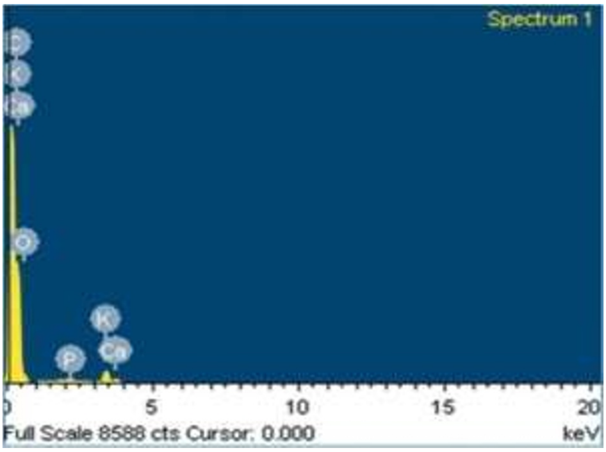

Fig. 1. EDAX Elemental Composition of palm kernel shell into ash samples

Fig. 2. a) Micro-hardness Test Samples of Hybrid Metal Matrix composites b) Tensile test specimens

3 The Findings And Further Analysis

3.1. Endurance under tension as well as fractography

With the inclusion of palm kernel shell ash at a weight percentage of up to 5 wt%, the Ultimate Tensile Strength (UTS) of the hybrid composite was shown to be improved, as shown in Figure 3. The increased strength is most likely the result of a number of different strengthening processes, as shown by earlier studies[17]. These mechanisms suggest that high-strength reinforcement particles directly fortify the material by transferring load from the weaker metal matrix. Because of this process, dislocations are prevented, which results in improved strength. Indirect strengthening occurs as a consequence of thermal mismatch, which is caused by the fact that the melting temperatures and rates of thermal expansion of mineral matrix and ceramic particles are different from one another. Tensile qualities, on the other hand, are somewhat diminished when palm kernel shell ash is used as a reinforcing material. It is possible that this is due to an increased $CaCO_3$ concentration as well as an uneven distribution of particles, which ultimately results in a less satisfactory interaction between the particles and the matrix [18].

3.2. Effect of hybrid reinforcement on the UTS and Elongation of the composites

One way to shed light on this is to take into consideration the increased concentration of palm kernel shell ash that is present in the hybrid reinforcement. The rise in the amount of reinforcing particles is directly related to the reduction in elongation that occurs progressively. The cumulative impact of silicon carbide, as well as a rise in titanium dioxide and palm kernel shell ash, are all possible causes for this phenomenon[19,20].

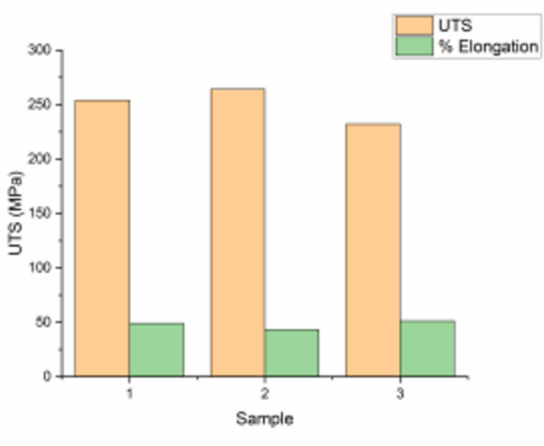

Fig. 3. Hybrid reinforcements affect composite UTS and Elongation.

3.3. Micro hardness

Due to the incorporation of nanoparticles into the hybrid material, the overall micro-hardness, particularly was tested at 96, 106, and 101 VHN and is represented in Exhibit 4, demonstrated an increase. The researcher observed a rise in the hardness value that corresponded to the increase. However, when palm kernel shell ash was present at a volume percentage of 5, a decrease in micro-hardness was detected that was statistically significant. [20].

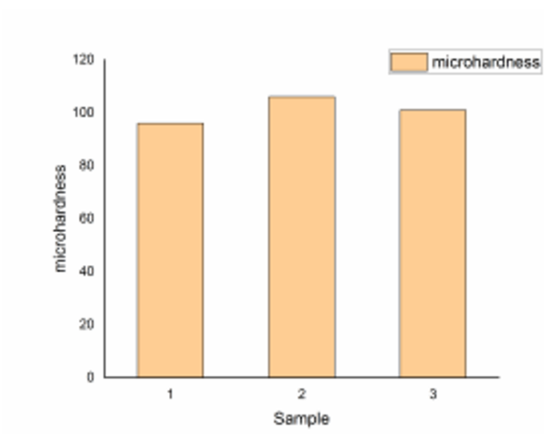

Fig. 4. Hybrid reinforcement affects composite microhardness

3.4. Effect of hybrid reinforcement on the Micro hardness of the composites

When applied to a particular region, the combined reinforcements display a performance that is comparable to the heterogeneous precipitation that takes place in a liquid puddle that is composed of liquid aluminium. One possible explanation for the extraordinary hardness of these mixed granules is that the hybrid aluminium alloy has a higher bearing load capacity than other alloys [21]. In spite of this, it is possible to see a notable decrease in the micro-hardness of the material as their concentration level rises. There is a possibility that the occurrence might be related to the agglomeration of particles that have been reinforced. In addition to being composed of calcium carbonate, palm kernel shell ash is a component that contributes to the development of permeability, which ultimately results in the formation of gaps. There is a tendency for these gaps to function as initiation places for fractures, which may possibly advance the overall course of the fracture but eventually result in a reduction in the total micro-hardness [22,23].

3.5. Wear rate

Figure 5 is a representation of the topography of the exterior of the eroded areas that surround its structure. During the whole of the elevated process, the adhesive backing approach was found to be very prevalent in the alloys that were produced. The development of backing segments, in particular during sliding operations, was a clear example of this strategy [24]. When exposed to high temperatures, a protective silicon film grows on the surface of the metal hybrid composite that is created. This film acts as a barrier against the fatal oxidation of the metal. The researchers came to the conclusion that raising the weight % of silicon carbide reinforcements led to a decrease in the production of grooves and cracks on the composite material, which in turn greatly slowed down the wear rate. This conclusion was based on significant data. In addition, the integration of carbon atoms has the effect of causing calcium carbonate to perform the role of a lubricating fluid, which contributes to a reduction in the total degradation ratio.

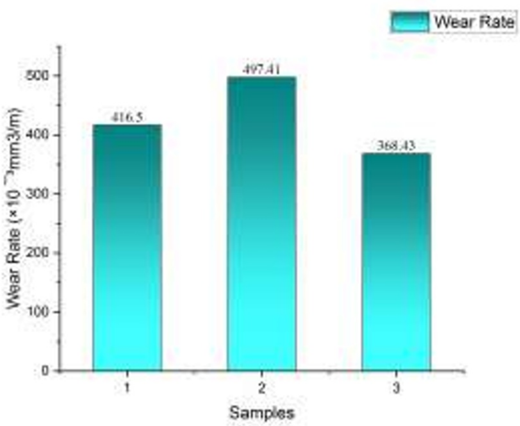

Fig. 5. Hybrid reinforcement affects composite wear.

4 Microstructure Analysis

FESEM micrographs of a) Sample 1 b) Sample 2 c) Sample 3

Figure 6(a-c) illustrates the consistent structure that is typical of aluminum-metal substrate alloys over a variety of mixed reinforcement ratios throughout the board. Within the aluminium substrate, the photos demonstrate the correct distribution of reinforcements and their placement. The presence of pores in the photographs, which are typically seen in photos taken with a scanning electron microscope, gives rise to the possibility that these pores are an artefact generated by the incorporation of palm kernel shell ash. The insertion of particles made of either titanium dioxide or silicon carbide offers a significant contribution to the enhancement of the characteristics [25].

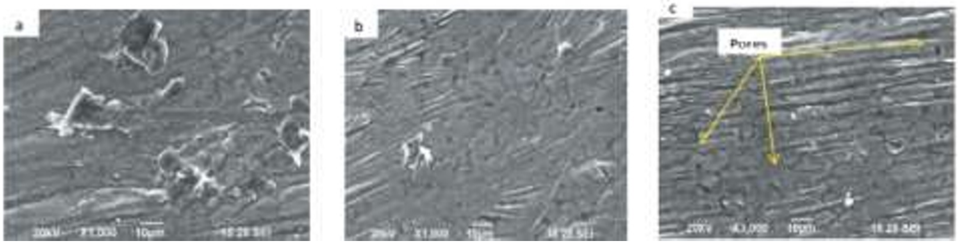

Fig. 6. Micrographs taken using a FESEM

5 Conclusions

Using mixed reinforcements to fabricate Al-7075 reinforced by the use of swirl castings proven to be an efficient solution. This investigation's results revealed that the following:

- Sample 2, out of all the samples that were analysed, had the highest mechanical endurance. The tensile strength of the composite, on the other hand, has the potential to greatly improve in comparison to the alloy that it was originally made from. It had been feasible to evaluate the impacts since they had included a reinforcing component that was naturally present in the environment.
- The two objects in question had the highest possible value throughout the Hardness parameter. The quantity of growth that had occurred in relation to the material that was initially there was significant. The results of the EDAX test indicate that it would be possible to explain it by the quantity of carbon atoms that were discovered in the seed ash of the plant specimen.
- Given the importance of the third sample, it is significant that it had the lowest percentage of deterioration that was identified during the whole process. These might occur as a result of the presence of carbon, which not only creates a coating that protects the metal from oxidation but also acts as a shield that helps slow down the overall pace of degradation.
- An study employing a scanning electron microscope revealed that the nanocomposite material has porosity. Every instance of calcium that is present in the reinforcing nanoparticle has the potential to be responsible for the formation of pores. When it comes to the creation of aluminium foams, the following procedure has the potential to be much more successful than other approaches.

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