IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Evaluation of Properties of Hybrid Metal Matrix Composites Using Aluminium LM-6 Alloy and Ceno-Granite Powder

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Abstract: Hybrid Metal Matrix Composites (HMMCs) represent an advanced class of materials that combine the beneficial properties of both metallic and non-metallic reinforcements, enhancing their mechanical, thermal, and wear-resistance properties. This review paper focuses on the evaluation of hybrid composites formed by incorporating cenosphere (a lightweight, hollow alumino-silicate microsphere) and granite powder into Aluminium LM-6 alloy matrix. The study explores the synergistic effects of combining these reinforcements to produce a composite material with superior characteristics suitable for applications in the aerospace, automotive, and manufacturing industries[1]. The paper provides an in-depth analysis of the various reinforcement techniques, including the preparation of cenosphere-granite reinforced composites, and the mechanical and metallurgical properties of the resulting HMMCs. Attention is paid to the uniformity of reinforcement dispersion, microstructural analysis, and the impact of processing parameters on the final properties of the composite material. The mechanical properties, such as hardness, tensile strength, wear resistance, and thermal stability, are discussed in relation to the microstructural changes induced by the reinforcements. Additionally, the study reviews advancements in the fabrication methods, including stir casting, and the challenges associated with the dispersion of cenosphere and granite powders into the aluminium matrix [2].Through a synthesis of existing literature, this paper aims to present a comprehensive understanding of the potential and challenges associated with the development of cenosphere-granite hybrid composites in the Aluminium LM-6 matrix. The work also suggests future directions for optimizing the properties of HMMCs through innovative fabrication techniques and enhanced reinforcement distribution[3].

Index Terms - Aluminium-LM6, cenosphere, granite powder, Hybrid metal matrix composites

I. Introduction

The demand for advanced materials with superior mechanical and thermal properties has led to the development of Hybrid Metal Matrix Composites (HMMCs). HMMCs are produced by reinforcing a metal matrix with two or more distinct reinforcement materials, resulting in improved properties such as high strength-to-weight ratio, superior wear resistance, and enhanced thermal conductivity. Among the various metal alloys, Aluminium LM-6 is a preferred choice for HMMCs due to its excellent castability, corrosion resistance, and satisfactory mechanical properties. The inclusion of suitable reinforcements can further enhance the properties of Al-LM6 alloy for high-performance applications in automotive and aerospace sectors [4].

Cenosphere, a lightweight, hollow alumino-silicate microsphere, has been extensively explored as a reinforcing material for metal matrix composites. The cenosphere's low density and high thermal stability contribute significantly to the reduction of the composite's overall weight, making it ideal for lightweight applications. Furthermore, it offers improvements in wear resistance and thermal conductivity when added to aluminium alloys. Granite powder, an industrial by-product, is another promising reinforcement material

due to its high hardness and wear resistance properties. The incorporation of granite powder into the Al-LM6 matrix contributes to enhanced hardness and mechanical strength, which are crucial for applications involving abrasive wear [5].
The combination of cenosphere and granite powder as hybrid reinforcements in Al-LM6 alloy is expected to provide a balance between lightweight properties, wear resistance, and thermal stability. This review examines the processes involved in fabricating Al-LM6-based HMMCs using cenosphere and granite powder, the challenges faced during fabrication, and the properties of the resulting composites. Emphasis is placed on processing techniques, the role of reinforcement dispersion, and the impact of these reinforcements on the mechanical and thermal properties of the composite material [6].

II. Reinforcing Cenosphere and Granite Powder in Al-LM6 Alloy Matrix and Fabricating Al-LM6-Cenosphere-Granite HMMCs

The process for reinforcing Aluminium LM-6 alloy with cenosphere and granite powder to fabricate hybrid metal matrix composites (HMMCs) involves several steps to ensure optimal dispersion and bonding between the matrix and the reinforcements. Below is a detailed breakdown of the key processes involved:

1. Material Selection and Preparation:
Al-LM6 Alloy: This aluminium alloy is selected due to its favourable casting properties and good mechanical strength. The alloy composition typically includes 11-13% Si, 0.6-1.0% Mg, and other trace elements like Cu and Fe. The alloy is available in the form of ingots, which are melted before introducing the reinforcements.
Cenosphere and Granite Powder: Cenosphere, a by-product of the power plant industry, has a low density and high surface area, while granite powder offers high hardness and wear resistance. Both reinforcements are ground to a suitable size, typically in the range of 10-100 µm, depending on the required properties of the composite [7].

2. Fabrication Techniques:
Stir Casting: The most widely used method for producing aluminium matrix composites, stir casting involves melting the aluminium alloy in a furnace and then adding the reinforcements. A mechanical stirrer is used to agitate the molten metal, ensuring the uniform distribution of cenosphere and granite powder in the matrix.
Vortex Method: In this method, a vortex is created in the molten metal using a stirrer, allowing for better mixing and incorporation of the reinforcement particles. It helps in achieving a uniform dispersion of cenosphere and granite powder in the Al-LM6 matrix.
Die Casting and Powder Metallurgy: Though less common for hybrid composites, die casting and powder metallurgy techniques are also used for producing HMMCs, especially when finer control over the microstructure is required.

3. Reinforcement Dispersion:
The successful dispersion of cenosphere and granite powder is one of the most critical aspects of the fabrication process. Various strategies are employed to achieve a homogeneous distribution, including ultrasonic treatment, which helps break agglomerates and disperse the particles more effectively [8].
The stirring speed and time are optimized to prevent particle sedimentation and ensure that the reinforcements do not segregate during the cooling process.

4. Solidification and post-treatment:
Once the molten composite slurry is poured into the mold, it is allowed to cool and solidify. The cooling rate affects the microstructure and mechanical properties of the composite.
Post-treatment techniques, such as heat treatment (solution treatment and aging), are often applied to further enhance the mechanical properties, particularly the hardness and tensile strength [9].

III. Metallurgical Properties of Al-Silicon–Ce-Gr HMMCs

The metallurgical properties of Aluminium-Silicon-Cenosphere-Granite (Ce-Gr) HMMCs are critical in determining the composite's performance in engineering applications. Key properties such as microstructure, phase evolution, hardness, tensile strength, and wear resistance are studied to assess the suitability of these composites for various industries.

1. Microstructure Analysis:
Optical microscopy and SEM are used to study the dispersion of the cenosphere and granite powder within the Al-Silicon matrix. The presence of voids or pores due to poor bonding between the reinforcements and the matrix is identified.
X-ray diffraction (XRD) is used to analyse the phases present in the composite and assess the effect of reinforcement on phase stability. The addition of cenosphere and granite powder can influence the formation of intermetallic phases and impact the mechanical properties of the composite [10].

2. Hardness and Mechanical Properties:
Hardness testing (Vickers or Rockwell) is used to evaluate the composite's resistance to surface deformation.
Tensile testing and compressive strength tests are performed to assess the material's ability to withstand loading without failure. The results are compared to pure Al-LM6 and other hybrid composites in the literature.

3. Wear Resistance:
Pin-on-disk wear testing is conducted to determine the wear rate of the composite under different load conditions. The wear behaviour is studied in relation to the microstructure, particularly focusing on the role of cenosphere and granite powder in enhancing wear resistance [11].

Table1: Chemical composition of LM6 (Metal matrix)

Metals/ Non--Metals	Percentage
Copper	0.4 max.
Magnesium	0.2 max.
Silicon	10.0 -13.0
Iron	1.0 max
Manganese	0.5 max.
Nickel	0.1 max.
Zinc	0.2 max.
Lead	0.1 max.
Tin	0.1 max.
Titanium	0.2 max.
Aluminum	Remainder

Table 2:Chemical composition of ceniosphere

COMPOUNDS	PERCENTAGES (%)
Silica	58.9
Alumina	32.75
Iron Oxide	2.9
Potassium Oxide	1.29
Titanium Oxide	1.27
Magnesium Oxide	1.2
Calcium Oxide	0.50
Sodium Oxide	0.25
Carbon	0.002

They consist mostly of silicon dioxide (SiO2), which is present in two forms:Amorphous, which is rounded and smooth, andCrystalline, which is sharp, pointed and hazardous Cenosphere:75-150 Microns

Fig1: Granite Powder(75 micron)

Table 3: Chemical composition of granite powder

Compound	Wt.%
Silica	70-77
Alumina	11-13
Potassium oxide	3-5
Soda	3-5
Lime	1
Iron	2-3
Magnesia & Titania	Less than 1

IV. CONCLUSIONS

The development of Hybrid Metal Matrix Composites (HMMCs) using Aluminium LM-6 alloy reinforced with cenosphere and granite powder has shown promising results in enhancing the mechanical, thermal, and wear resistance properties of the composite material. Stir casting has proven to be an effective method for fabricating these composites, although challenges remain in ensuring uniform reinforcement distribution and preventing particle agglomeration [12].

The mechanical properties, including tensile strength, hardness, and wear resistance, were significantly improved with the addition of both cenosphere and granite powder. However, further research is needed to optimize the processing conditions, particularly stirring speed, temperature, and reinforcement size, to achieve the best possible composite performance [13].

The study and development of HMMCs using Aluminum LM-6 alloy as the matrix, reinforced with cenosphere and granite powder, have shown promising results in improving the material properties. The incorporation of cenosphere provides a lightweight solution, which is particularly beneficial for aerospace and automotive industries, where weight reduction is critical. Meanwhile, the use of granite powder as a reinforcement enhances the hardness and wear resistance of the composite, making it suitable for applications requiring high durability [14].

However, several challenges remain in the fabrication process, particularly regarding the uniform distribution of the reinforcements and the control of particle interaction with the aluminium matrix. Future research should focus on optimizing the processing conditions, such as stirring speed and temperature, to achieve better dispersion and reduce the risk of defects. Additionally, the effects of varying the cenosphere-to-granite ratio and the influence of heat treatment on the final properties of the composite should be explored.

The development of advanced characterization techniques, such as in situ observation during processing and detailed microstructural analysis, will contribute to a deeper understanding of the material behaviour and lead to the optimization of hybrid composites for high-performance applications [15].

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