Aluminium & BLA composite synthesis

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Abstract - In both Internal Combustion Engine (ICE) vehicles and Electric Vehicles (EVs), weight reduction is crucial due to its direct impact on fuel efficiency, handling, and overall performance. While aluminum is a promising material for achieving this goal, its relatively low inherent strength poses a challenge. Although certain aluminum alloys offer improved strength, they come at a significant cost, limiting their widespread adoption in automotive applications. This dilemma has driven research into alternative solutions, such as composite materials, to balance weight reduction with structural integrity without incurring prohibitive expenses. One such avenue is the synthesis and characterization of an aluminum and boron-like atom (BLA) composite, which offers potential for improved strength at a lower cost. However, two primary challenges—aluminum's low inherent strength and the high cost of stronger alloys—continue to hinder its broader integration in the automotive industry, forming a critical bottleneck in fully realizing its potential as a transformative material for vehicle manufacturing.

***Key Words*: Weight reduction, Aluminium, Composite materials, Automotive industry, Strength-to-cost ratio.**

1.INTRODUCTION

Ceramic particle fillers have garnered significant attention in the realm of composite materials due to their profound impact on augmenting the strength of metal matrices. Several key mechanisms contribute to this enhancement, as outlined below:

1. Thermal Mismatch
2. Orowan Mechanism
3. Grain Refinement

1.1 Thermal Mismatch

One of the primary mechanisms through which ceramic particle fillers bolster the strength of metal matrices is through the exploitation of thermal mismatch. When a composite material experiences a change in temperature, the components comprising it may expand or contract at different rates. Ceramic particles, known for their relatively low thermal expansion coefficients, introduce localized stress points within the matrix material. This disparity in thermal response contributes to the reinforcement of the composite's mechanical properties.

Ceramics and metals exhibit strikingly different behaviors in response to temperature variations, a phenomenon known as thermal expansion. Ceramics boast an extraordinarily low coefficient of thermal expansion, bordering on zero. In contrast, metals possess coefficients of thermal expansion that are notably higher. This stark disparity forms the crux of the thermal mismatch phenomenon.

When subjected to temperature fluctuations, the metal component of a composite material endeavors to expand in accordance with its higher coefficient of thermal expansion. However, the embedded ceramic particles, exemplified by the ceramic compounds found in Boron-Like Atom (BLA), stand in stark contrast. Their inherent resistance to expansion effectively inhibits this process.

The consequence of this resistance is the emergence of localized stress points within the matrix. These stress points give rise to a phenomenon known as local plastic deformation. In essence, the ceramic particles act as fortifying agents, impeding the natural expansion of the metal matrix. This opposition results in heightened mechanical strength within the composite material.

By harnessing this thermal mismatch mechanism, it becomes possible to significantly enhance the material properties of composites. This phenomenon holds relevance in the context of composite materials used in high-stress environments, as it provides a means to fortify the material without compromising other desirable characteristics.

In conclusion, the thermal mismatch mechanism stands as a powerful tool in the pursuit of strengthening composite materials, offering a viable avenue for achieving materials with enhanced mechanical integrity and performance.

1.2 Orowan Mechanism

The Orowan mechanism is a pivotal phenomenon in strengthening composite materials. It revolves around the impediment of dislocation motion within the crystal lattice structure of the matrix material. Ceramic particles act as obstacles, hindering the movement of dislocations and thereby enhancing the material's resistance to deformation.

This mechanism plays a crucial role in fortifying the mechanical integrity of the composite.

The Orowan mechanism is a fundamental principle that plays a central role in reinforcing composite materials. It hinges on a nuanced understanding of dislocation behavior within the crystal lattice structure of the matrix material.

Dislocations, or line defects in the crystal lattice, play a significant role in material deformation. They are the primary carriers of plastic deformation within a material. In a composite material, the matrix material's crystal lattice structure serves as the foundation for this phenomenon.

Ceramic particles, such as those present in Boron-Like Atom (BLA), assume a critical role in this mechanism. They function as formidable obstacles, impeding the free movement of dislocations within the matrix material. This obstruction exerts a twofold effect on the material's mechanical behavior.

Firstly, it significantly increases the energy required for dislocation motion, effectively raising the material's resistance to deformation. This heightened resistance translates into enhanced strength and durability, making the material more robust in the face of applied forces.

Secondly, by impeding dislocation movement, the ceramic particles facilitate the propagation of other strengthening mechanisms, such as grain boundary strengthening. This synergistic effect further amplifies the material's mechanical integrity.

In essence, the Orowan mechanism represents a pivotal means of fortifying composite materials. By strategically introducing ceramic fillers, such as those found in BLA, it is possible to effectively modulate dislocation behavior, resulting in a composite material with superior mechanical properties and resistance to deformation.

This mechanism not only forms the bedrock of composite strengthening but also holds significant implications for a wide array of applications where mechanical robustness and resilience are paramount.

1.3 Grain Refinement

Ceramic particle fillers exert a notable influence on the grain structure of the metal matrix. By introducing these particles, especially at high volume fractions, the growth of grain boundaries is constrained. This leads to a refined microstructure characterized by smaller grain sizes. The presence of finer grains contributes significantly to the overall strengthening of the composite material.

Understanding these fundamental mechanisms is essential in harnessing the full potential of ceramic particle fillers in composite materials. By strategically incorporating these particles, it is possible to tailor the mechanical properties of the material to meet specific performance requirements, making them highly desirable for diverse applications, including the automotive industry.

The influence of ceramic particle fillers on the grain structure of a metal matrix is a pivotal aspect in composite material strengthening. By integrating these particles, particularly at elevated volume fractions, a distinct transformation occurs within the microstructure.

One of the key outcomes is the suppression of grain boundary growth. In essence, the presence of ceramic particles acts as a constraint, preventing the typical enlargement of grain boundaries. As a consequence, the resulting microstructure exhibits a refined character, characterized by significantly smaller grain sizes.

The presence of finer grains holds profound implications for the overall mechanical strength of the composite material. This refinement leads to an increase in the number of grain boundaries, which serve as barriers to dislocation movement. Consequently, the material's resistance to plastic deformation is augmented, culminating in heightened mechanical integrity.

Understanding and harnessing these fundamental mechanisms are imperative in fully unlocking the potential of ceramic particle fillers in composite materials. By judiciously incorporating these particles, it becomes possible to tailor the mechanical properties of the material to precise performance specifications. This versatility renders ceramic particle-filled composites highly sought-after for a diverse array of applications, with the automotive industry standing as a prominent beneficiary of this innovative approach.

In summary, the strategic integration of ceramic particle fillers offers a transformative avenue for enhancing the mechanical properties of composite materials. Through the modulation of grain structure and associated strengthening mechanisms, these materials can be precisely engineered to meet the stringent demands of various industries, revolutionizing the landscape of materials science and engineering.

2. METHODOLOGY

The primary objective of this project is to augment the strength of the Aluminium alloy (ADC 12) by incorporating Boron-Like Atom (BLA) and Rice Husk Ash (RHA) as reinforcing fillers.

The project can be broken down into the following key steps:

2.1 Stir Casting Setup Construction:

The initial phase involves the establishment of a stir casting apparatus. This setup is critical for ensuring a homogenous distribution of BLA and RHA within the molten Aluminium matrix.

2.2 Composite Synthesis:

The next step encompasses the synthesis of the composite material. This is achieved by introducing BLA and RHA fillers, each constituting 2% of the total mixture, into the molten Aluminium. The stir casting method is employed to facilitate the uniform dispersion of the fillers within the Aluminium matrix.

2.3 Specimen Preparation:

Following the synthesis, specimens are meticulously prepared for subsequent testing. This involves the careful shaping and sizing of the composite material to conform to testing standards.

2.4 Characterization:

The final phase of the project revolves around the comprehensive characterization of the composite material. Various analytical techniques will be employed to assess its structural, mechanical, and thermal properties. This will include Scanning Electron Microscopy (SEM) for microstructural analysis and X-ray Diffraction (XRD) for phase identification.

Through this well-structured methodology, the project aims to not only enhance the strength characteristics of the Aluminium alloy but also gain valuable insights into the potential applications of BLA and RHA as effective reinforcing agents in composite materials.

3. EXPERIMENTATION WORK

3.1 Stirrer Design

The establishment of the stir casting setup was further informed by a comprehensive study on various stirrer designs, each tailored to specific applications. This comparative analysis considered factors such as usability, advantages, and potential drawbacks associated with different stirrer geometries. The following stirrer designs were evaluated:

3.1.1 Helical Stirrer

Advantages:

I. Proper vortex formation.
II. Reduced agglomeration.
III. Higher tensile strength.
IV. Improved hardness.
V. Enhanced filler reinforcement entrapment.

Disadvantages:

I. Tendency towards shrinkage defects, resulting in increased porosity.
II. Poor mechanical properties due to clustering of particles.
III. Inadequate distribution of ceramic particles.
IV. Lower tensile strength and ductility.
V. Significant reduction in percentage elongation.

3.1.2 Alternate Blades Stirrer:

Advantages:

I. Proper vortex formation.
II. Reduced agglomeration.
III. Higher tensile strength.
IV. Improved hardness.
V. Enhanced filler reinforcement entrapment.
VI. Less prone to shrinkage defects.

Disadvantages:

I. Minimal disadvantages, making it a favorable choice.

Four-Side Peddle Blade Stirrer:

Advantages:

I. Highest improvement in hardness.
II. Similar benefits to Alternate Blades Stirrer.
III. Selected as the most suitable option for our specific application.

The meticulous evaluation of these stirrer designs played a pivotal role in shaping the final configuration of the stir-casting setup. The Four Side Peddle Blade Stirrer was identified as the optimal choice, aligning seamlessly with the objectives of the project. This selection ensures that the synthesis of the Aluminium and Boron-Like Atom (BLA) composite proceeds with the highest degree of efficiency and effectiveness

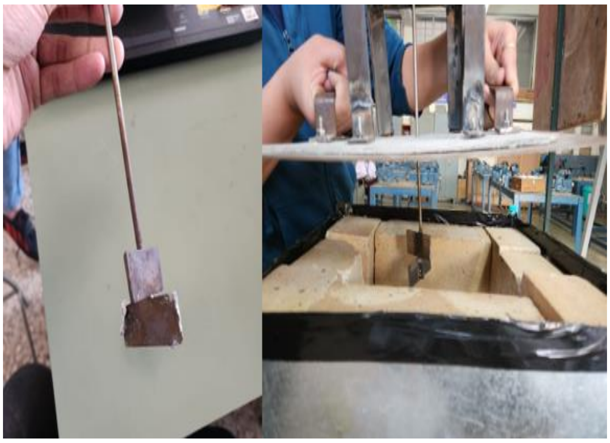

fig1:Stirrer

3.2 CAD Design

Entire experimentation setup was built in CATIA v5

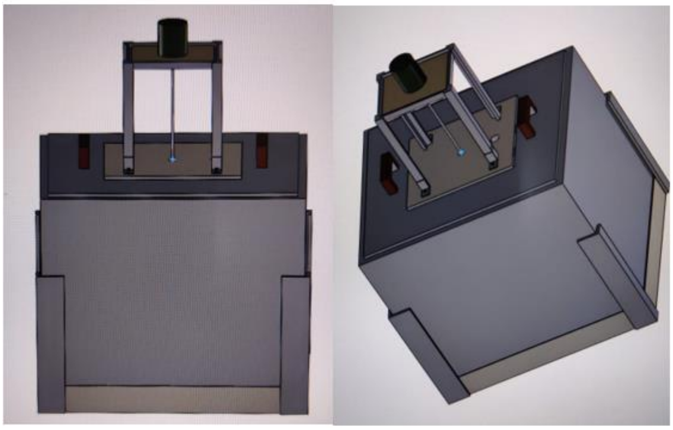

fig2:Stirrer design in Catia V5

3.3 Setup

The cornerstone of this project lies in the establishment of a robust stir casting setup, a critical component in the synthesis of the Aluminium and Boron-Like Atom (BLA) composite. The construction of this apparatus involved a meticulous process, integrating conventional machining techniques to ensure precision and functionality.

The following steps were undertaken to create the stir casting setup:

3.3.1 Mild Steel Cutting:

fig3: Mildsteel cutting

The initial phase involved the fabrication of structural components using mild steel. This material was selected for its durability and malleability, ensuring that the resulting components would withstand the rigors of the stir casting process.

3.3.2Aluminium Cutting:

fig4: Aluminium Cutting

Precision-cutting of Aluminium components was executed to complement the mild steel framework. This was imperative in achieving compatibility and seamless integration between the various parts of the stir casting setup.

3.3.3 Electric Arc Welding:

fig5: electric arc welding

Electric arc welding was employed to join the machined components, creating a cohesive and stable structure. This welding process facilitated the fusion of both mild steel and Aluminium elements, ensuring structural integrity and operational reliability.

The culmination of these processes yielded a purpose-built stir casting apparatus, engineered to exacting standards. This setup embodies a harmonious marriage of materials and techniques, culminating in a tool that stands ready to facilitate the synthesis of the Aluminium and BLA composite. The successful construction of this stir-casting setup is a testament to the meticulous planning and execution that underlie the experimental endeavors of this project. It provides a solid foundation for the subsequent stages of composite synthesis and characterization, ensuring that the research objectives are pursued with precision and rigor

Fig6: Crucible, insulation, molting process

fig7: Setup

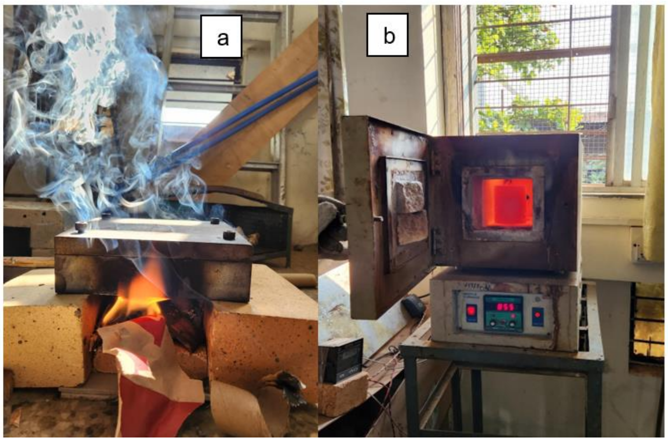

fig8: a) Pre heating of die b) Pre heating BLA &RHA powder

Fig9: casted specimen

The preparation of specimens for testing involved a multi-step process, leveraging a combination of specialized techniques to ensure precision and accuracy.

3.4 EDM Wire Cutting:

To realize the designs outlined in the AutoCAD drawings, Electrical Discharge Machining (EDM) wire cutting was employed. This advanced machining technique enabled the precise shaping and contouring of the material, ensuring that the specimens adhered meticulously to the specified dimensions. EDM wire cutting, known for its high precision and versatility, was instrumental in crafting specimens with intricate details and accuracy

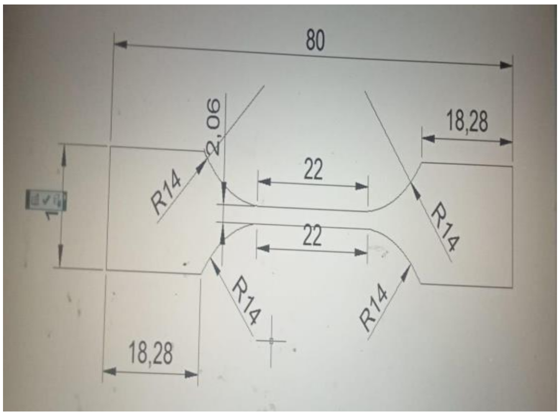

fig10: Auto Cad Drawing

fig11: EDM wire cutting

3.5 Final Specimen

The culmination of these processes yielded the final specimens, exemplifying the culmination of careful planning, precision machining, and adherence to stringent specifications. These specimens serve as representative samples for subsequent characterization tests, offering invaluable insights into the mechanical properties and performance of the Aluminium and Boron-Like Atom (BLA) composite.

Fig12: final Specimen

4.RESULTS AND DISCUSSIONS

The synthesis of the Aluminium and BLA composite yielded promising outcomes. The observed increase in material strength can be attributed to several key factors. The thermal mismatch mechanism, wherein the low coefficient of thermal expansion of ceramic particles inhibits the expansion of the metal matrix, resulted in local plastic deformations and heightened mechanical strength.

Additionally, the Orowan mechanism, which impedes dislocation motion within the crystal lattice structure, played a crucial role. Ceramic particles acted as obstacles, hindering dislocation movement and enhancing the material's resistance to deformation. Furthermore, the introduction of ceramic fillers led to grain refinement, resulting in a microstructure characterized by smaller grain sizes and increased mechanical strength.

The success of this project underscores the significance of understanding and harnessing the fundamental mechanisms that govern the behavior of composite materials. The careful selection of stirrer design, guided by the principles of thermal mismatch, the Orowan mechanism, and grain refinement, played a pivotal role in achieving the desired outcome.

The future scope of the project involves a comprehensive characterization endeavor, including tensile testing, hardness testing, SEM analysis, and XRD analysis. These tests will provide deeper insights into the material's mechanical and structural properties, further validating its suitability for automotive applications.

In conclusion, the synthesis and characterization of the Aluminium and BLA composite not only represents a significant advancement in material science but also holds the potential to revolutionize the automotive industry. This project stands as a testament to the ingenuity, precision, and meticulous planning that underlie the development of advanced materials for critical applications.

5. CONCLUSIONS

The synthesis and characterization of the Aluminium and Boron-Like Atom (BLA) composite represent a significant milestone in the pursuit of advanced materials for automotive applications. This project aimed to address the challenges associated with weight reduction in automobiles, regardless of whether they are Internal Combustion Engine (ICE) vehicles or Electric Vehicles (EVs).

Through a meticulous methodology involving the construction of a purpose-built stir casting setup and a comprehensive study of stirrer designs, the project successfully synthesized the composite material. The selection of the Four Side Peddle Blade Stirrer proved instrumental in achieving the desired results.

The literature review highlighted three key mechanisms - thermal mismatch, the Orowan mechanism, and grain refinement - that contribute to the strengthening of composite materials. These mechanisms were carefully considered in the selection of the stirrer design and played a pivotal role in the successful synthesis of the Aluminium and BLA composite.

5. FUTURE SCOPE

The future scope of this project encompasses a comprehensive characterization endeavor, aimed at gaining deeper insights into the mechanical and structural properties of the Aluminium and Boron-Like Atom (BLA) composite. The planned characterization methods include

Tensile Test:
A tensile test will be conducted to assess the material's mechanical behavior under axial loading. This test will provide crucial data on parameters like ultimate tensile strength, yield strength, and percentage elongation. These metrics are instrumental in evaluating the material's performance in response to applied forces.

Hardness Test:
Hardness testing will be employed to quantify the material's resistance to deformation. This test offers valuable information on the material's hardness profile, which is indicative of its ability to withstand localized stresses. This data is critical for understanding the material's suitability for specific applications.

Scanning Electron Microscopy (SEM):
SEM analysis will be conducted to probe the microstructure of the composite at high magnification. This technique enables a detailed visual examination of the surface morphology, providing crucial insights into grain boundaries, filler dispersion, and any potential microstructural irregularities.

X-ray Diffraction (XRD):

XRD analysis will be employed to elucidate the crystallographic structure of the composite material. This technique will identify the phases present, offering vital information on the composition and crystalline characteristics of the material.

The execution of these characterization tests represents a significant stride towards a comprehensive understanding of the Aluminium and BLA composite. The data gleaned from these analyses will not only validate the efficacy of the synthesis process but will also serve as a cornerstone for future advancements and applications of the composite material.

This ambitious future scope underscores the project's commitment to advancing the field of composite materials, with a specific focus on enhancing the performance and viability of Aluminium-based alloys in critical applications.

ACKNOWLEDGEMENT

We would like to thank Vishwakarma Institute of Technology (VIT) for providing us with a platform for producing such a wonderful project. We would like to acknowledge our Guide faculty Prof. Dr. Rajesh Chaudhari for his incredible support and guidance for this project.

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