# Development, Characterization of Ultrasonic- Assisted Stir-Squeeze Cast Al7075/Sic Composite

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## ABSTRACT:

Aluminum metal parts are increasingly being used in the automotive industry in place of ferrous materials in an effort to reduce weight and pollution. At the same time, aluminum and its composites are being used more frequently in the aerospace and marine industries due to their lightweight nature and good corrosive qualities. Aluminum-based metal matrix composites have received a lot of attention in research and development because of their remarkable mechanical qualities and prospective uses in the automotive and aerospace industries. This study offers a comprehensive examination of the manufacturing techniques and mechanical testing associated with advanced aluminum metal matrix composites. By reviewing existing literature, the paper explores the different reinforcement materials, processing methods, and characterization techniques employed to enhance the mechanical performance of these composite materials.

**Keywords: Aluminum Metal Matrix Composites, Solid State Processing, Liquid State processing, Electron Microscopy, Strength to Weight Ratio**

## INTRODUCTION:

Composites progress has been motivated by the desire of lightweight, high-strength, and customizable materials that can outperform traditional engineering counterparts. Advances in material science, manufacturing techniques, and computational modeling have all contributed to the steady progress regarding composite materials. The widespread adoption of composites can be largely attributed to their customizable nature, enabling engineers to fine-tune material properties to align with the specific needs of their projects. [1]. Composites can be categorized in a general sense according to the nature of their reinforcing elements, which can be fibers, particles, or a combination thereof. Fiber-reinforced composites, for instance, leverage the inherent strength and stiffness of fibers to enhance the overall mechanical performance of the material, while particle-reinforced composites often exhibit improved wear resistance and thermal properties. Beyond the classification based on reinforcement, composites can also be distinguished by their matrix materials, which can be polymers, metals, or ceramics. The choice of matrix material is crucial, as it influences both the overall properties of the composite and the manufacturing process, as well as the final application.

[2] Engineering design places significant emphasis on the mechanical properties of composites, including their impact resistance, compressive strength, and tensile strength.

By using the right matrix materials, production processes, and reinforcing elements, these qualities can be customized. Furthermore, composites can demonstrate advantageous properties such as reduced coefficient of thermal expansion, elevated thermal resistance, and enhanced damping capacities, rendering them appropriate for an extensive array of uses [3]. The significance of composites in engineering cannot be overstated. These materials have found widespread use in aerospace, automotive, construction, and biomedical industries, among others, because they can offer a weight, strength, and functional property balance that is favorable. For example, fiber-reinforced polymer composites have been widely used in the aerospace sector to create lightweight, high-performance aircraft components that result in increased fuel efficiency and lower emissions. In summary, the creation and use of composite materials have revolutionized the engineering field by providing professionals with an adaptable toolkit to handle ever advancing technologies.

## 1.ALUMINUM BASED METAL MATRIX COMPOSITES:

Aluminum-based metal matrix composites and nano composites have garnered considerable attention due to their exceptional characteristics, including high specific strength, superior thermal and electrical conductivity, and enhanced wear resistance. Aluminum alloys can be found in both wrought and cast forms.

Table 1.1 Details of Wrought Aluminum alloys

| S.No | Series | Alloying Element |
|---|---|---|
| 1 | 1000 | Pure |
| 2 | 2000 | Copper |
| 3 | 3000 | Manganese |
| 4 | 4000 | Silicon |
| 5 | 5000 | Magnesium |
| 6 | 6000 | Magnesium and Silicon |
| 7 | 7000 | Zinc |
| 8 | 8000 | Other Elements |

Table 1.2 Details of Cast Aluminum alloys

| S.No | Series | Alloying Element |
|---|---|---|
| 1 | 1000 | Pure |
| 2 | 2000 | Copper |
| 3 | 3000 | Silicon, with added Copper and/or Magnesium |
| 4 | 4000 | Silicon |
| 5 | 5000 | Magnesium |
| 6 | 6000 | Magnesium and Silicon |
| 7 | 7000 | Zinc |
| 8 | 8000 | Tin |
| 9 | 9000 | Other Elopements |

The remarkable properties exhibited by aluminum-based metal matrix composites, including their exceptional mechanical strength, superior thermal management capabilities,[4] and versatile applicability across a wide range of industries, have propelled these materials into the forefront of materials science and engineering research. Aluminum metal matrix composites have shown promise as an engineering solution for a range of applications, especially in the aerospace, automotive, and military industries where high-performance, lightweight materials are critical[5].

Table 3.3 commonly used AMMCs used in engineering application

| Matrix | Reinforcement | Improved Properties | Applications | Reference |
|---|---|---|---|---|
| Al6061 | SiC | Tensile Strength, Hardness, Wear Resistance, Density, Specific Stiffness | Piston, Brake Rotor, Liner, Propeller Shaft | [6] |
| A359 | $Al_2O_3$ | Compressive Strength, Wear Resistance | Piston Ring, Piston Crown | [7] |
| Al7075 | $B_4C$ | Reduced Friction, Wear, and Weight, Decrease in hardness | Cylinder Bearing | [8] |
| Al-Cu | Zr | Wear Resistance, Abrasion Resistance | Cutting tool, Impeller | [9] |

**1.1 Metal matrix composites that incorporate silicon carbide reinforcement within an aluminum matrix.**

The incorporation of reinforcements like silicon carbide, alumina, or graphite can significantly improve the mechanical characteristics of the aluminum matrix. This enhancement encompasses increased strength, stiffness, and wear resistance, all while maintaining a relatively stable composition [10, 11].

**1.2 Metal matrix composites reinforced with aluminum oxide derived from aluminum:**

The incorporation of aluminum oxide reinforcements into an aluminum matrix to make aluminum-based metal matrix composites has generated excitement among industry experts and researchers. These materials are particularly appealing for applications in the aerospace, automotive, and defense sectors because of their distinctive advantageous characteristics, such as superior thermal and electrical conductivity, increased wear resistance, and an excellent strength-to-weight ratio [12].
The properties of aluminum metal matrix composites are significantly influenced by the attributes of the reinforcing materials, including their volume fraction, size, and morphology within the aluminum matrix.

### 1.3 Aluminum-based metal matrix composites that incorporate boron carbide:

Aluminum and its alloys are extensively utilized in various engineering applications due to their outstanding workability, high thermal and electrical conductivity, and low density. The demand for materials that are both stronger and stiffer has driven the development of aluminum-based metal matrix composites, which are reinforced with various materials, including boron carbide (B4C).

Boron carbide, also known as B4C, is a type of ceramic material recognized for its outstanding hardness, thermal stability, and resistance to wear. When boron carbide particles are incorporated into an aluminum matrix, it can greatly enhance the strength, hardness, and thermal properties of the resulting composite material [13]. This has led to aluminum-boron carbide composites being considered as a promising option for use in the automotive, aerospace, and defense industries, where there is a high demand for high-performance structural materials [14].

Aluminum-boron carbide composites can be produced using different manufacturing methods, including stir casting, powder metallurgy, and in-situ synthesis.

### 1.4 Aluminum-based metal matrix composites reinforced with fibers:

The increase in the use of metal matrix composites based on aluminum can largely be attributed to their exceptional characteristics, rendering them an increasingly desirable material across a wide array of industries, most notably the automotive, aerospace, and transportation domains, where their lightweight and high-performance attributes are particularly valued. Aluminum-based metal matrix composites are composite materials that consist of an aluminum or aluminum alloy matrix reinforced with fibers [15], particles, or a combination thereof, usually made of ceramics, such as boron carbide, silicon carbide, or alumina, among other materials.

The primary reason for these improvements is the efficient load transmission from the aluminum matrix to the reinforcing materials, which have a higher stress tolerance than the aluminum alloy used in the base material. By changing the type, size, and volume percent of the reinforcement elements as well as the manufacturing processes employed in its creation, the aluminum metal matrix composite's unique characteristics can be tailored.[16]

### 1.5 Aluminum matrix composites enhanced with zircon reinforcement:

Metal matrix composites have recently garnered significant interest due to their highly customizable characteristics, making them suitable for a wide range of industrial uses. Notably, aluminum-based metal matrix composites, which are reinforced with different metallic and ceramic particles, have been widely utilized in the aerospace and automotive sectors. This is attributed to their enhanced resistance to corrosion, heat, and mechanical stress when compared to conventional aluminum alloys.

Given its capacity to improve the performance of metal matrix composites based on aluminum, zirconium diboride has garnered a great deal of interest as a reinforcing element [17] the exceptional characteristics of this material, including its elevated melting point, outstanding hardness, and impressive thermal and chemical stability, make it an ideal choice for enhancing aluminum alloys. Aluminum matrix composites have demonstrated improved mechanical properties, including higher strength, hardness, and wear resistance, as well as improved heat and corrosion resistance [18].

### 1.6 Aluminum-based metal matrix composites reinforced with industrial wastes and Agriculture wastes:

Hybrid aluminum composites use industrial and agricultural waste materials as primary or secondary reinforcing particles. Materials used may include fly ash, red mud, bean pod ash, groundnut shell ash, coconut shell ash, palm kernel shell ash, rice husk ash, bamboo leaf ash, and bagasse.

Table 1.6.1 Details of reinforcement, properties found, and tests conducted

| Reinforcing Element | Matrix | Properties Analyzed | Characterization and testing | Method of Fabrication | References |
|---|---|---|---|---|---|
| Fly Ash | $Al_2O_4$ | Microstructure Mechanical Physical | XRD SEM EDS Density Porosity Tensile Strength Hardness Fracture toughness | Stir Casting | [19] |
| SiC & $B_4C$ | Al7075 | Mechanical | Hardness | Stir Casting | [20] |
| SiC &RHA | Al356 | Microstructure Tribological | SEM EDS Density Porosity % elongation Tensile strength | Stir Casting | [21] |
| SiC & Mica | Al356 | Microstructure Physical Mechanical | SEM EDS Density Porosity | Stir Casting | [22] |
| $Al_2O_3$ Red-mud Graphite | Al6061 | Mechanical Tribological | Hardness CoF Wear rate | Stir Casting | [23] |
| $Al_2O_3$ RHA Graphite | Al-Mg-Si Alloy | Microstructure Mechanical Tribological | SEM EDS Hardness Tensile strength Wear rate | Double Stir Casting | [24] |
| Bagasse ash Graphite | Al7075 | Mechanical | Tensile strength Hardness Yield strength | Stir Casting | [25] |
| SiC $Al_2O_3$ | Al2024 | Mechanical | Tensile strength Ductility Hardness | Stir Casting | [26] |
| BLA RHA | AA6063 | Mechanical | Tensile strength Yield strength Hardness | Stir Casting | [27] |
| SiC , Fly ash Coconut coir ash | AA6061 | Microstructure Mechanical | SEM EDS Ultimate Tensile Strength Hardness | Stir Casting | [28] |
| $Al_2O_3$ SiC $CeO_2$ | AA6061 | Physical Mechanical | Density Porosity Tensile strength Hardness Ductility | Stir Casting | [29] |
| $Al_2O_3$ Bagasse ash | AA6061 | Mechanical | Tensile strength Hardness | Stir Casting | [30] |
| SiC $B_4C$ | AA6082-T6 Alloy | Microstructure Mechanical | SEM EDS Tensile strength Hardness | Stir Casting | [31] |

| | | | | | |
|---|---|---|---|---|---|
| | | | % elongation | | |
| $Al_2O_3$ SiC | Al7075 | Mechanical | Tensile strength Hardness | Stir Casting | [32] |

**1.6.1 Aluminum-based metal matrix composites reinforced with fly ash:**

In the fields of materials science and engineering, aluminum-based metal matrix composites are attracting significant interest due to their outstanding mechanical properties, enhanced wear resistance, and excellent thermal and electrical conductivity. This has led to a high demand for these materials across various industrial applications, especially within the automotive and aerospace industries. A notable approach for creating cost-effective and environmentally friendly composite materials involves the integration of fly ash, a byproduct from coal-fired power generation, into the aluminum matrix.

The fine, spherical particles of fly ash, a by-product of coal combustion, have the potential to serve as strong reinforcements in aluminum-based metal matrix composites. Fly ash reinforced composites demonstrate improved strength, stiffness, and fatigue resistance compared to the base aluminum alloy, characteristics that are essential for applications demanding lightweight and high-performance materials [33].

The production of aluminum composites reinforced with fly ash generally employs a range of processing methods, including stir casting, squeeze casting, and powder metallurgy.

These manufacturing methods facilitate the uniform dispersion of fly ash particles within the aluminum matrix, promoting effective load transfer and enhancing the mechanical characteristics of the composite.

Integrating fly ash into aluminum matrices enhances not only the mechanical properties but also tackles the environmental issues linked to the disposal of this industrial waste.

**1.6.2 Aluminum metal matrix composites reinforced with red mud:**

The aluminum industry generates a byproduct called red mud during the production of alumina. Annually, more than 120 million tons of red mud are produced [36-39] by the aluminum sector, with a yield of 1.5 tons of red mud for every 2.5 tons of alumina produced. Red mud, with a density of 3.05 g/cm3 [34], primarily consists of ferric oxide $Fe_2O3$, alumina $Al_2O_3$, and titanium oxide $TiO_2$.

Research has indicated that incorporating red mud as a reinforcing particle in aluminum alloys enhances the properties of Al-composites. Mujeeb et al. [35] utilized the stir-casting technique to fabricate hybrid composites of $Al_2O_3$ and AA6061 alloy containing red mud particles. As the weight fraction of the reinforcement particles increased, the hardness and tensile strength of the composites also increased proportionally. The use of red mud particles in Al6061 via stir casting resulted in improved hardness, wear rate, and coefficient of friction of the Al-composites due to good interfacial bonding [36].

**1.6.3 Aluminum based metal matrix composites reinforced with Bean Pod Ash (BPA):**

Parkia biglobosa beans undergo a process where the pods are split to extract the seeds and yellowish pulp. From every 100 kg of processed beans, 39 kg are obtained as bean pods [37]. The global generation of trash is significant and can lead to pollution if not effectively controlled. When this waste is burned, it produces bean pod ash, which can be utilized as a dye and in the production of black soap. The primary oxides in the ash include silica (SiO2), NaAlSi3O2, CaCO3, and Al4O4C. The incorporation of bean pod ash as particles enhances the properties of hybrid Al-composites.

### 1.6.4 Aluminum based metal matrix composites reinforced with Ground nut shell Ash (GSA):

Groundnut shell is an agro-waste material produced during the processing of peanuts or groundnuts from their nuts. Groundnut shells are abundant and sustainable, as around 16 million tons are produced globally each year [38]. Burning groundnut shells produces ash with $SiO_2$, $Al_2O_3$, and $Fe_2O_3$ as main elements.

### 1.6.5 Aluminum based metal matrix composites reinforced with Coconut shell Ash (CSA):

When coconut shells are burned, they emit methane and CO2, which contribute significantly to environmental pollution [39, 40,]. Coconut shell ash can serve as an effective reinforcement in hybrid aluminum composites. Coconut shell ash, with a density of 2.05 g/cm3, is effective for strengthening Al composites.

### 1.6.6 Aluminum based metal matrix composites reinforced with Palm kernel shell ash (PKSA):

Palm kernel shell, a byproduct of palm oil manufacturing, is abundant in Nigeria, Indonesia, Malaysia, and Brazil. In the palm oil production process, it is used as fuel in boilers to boil palm kernel oil [41, 42]. The palm kernel shell (PKS) is what remains after the kernel is detached from the hard, stony endocarp. This shell consists of 30% charcoal, 45% pyroligneous liquid, and 21% flammable gas [43]. When burned, palm kernel shell yields palm kernel shell ash (PKSA), which contains significant elements such as $SiO_2$, $Al_2O_3$, and $Fe_2O_3$. Due to its low density and composition, PKS is a suitable reinforcement material for hybrid aluminum composites [44].

### 1.6.7 Aluminum based metal matrix composites reinforced with Rice husk ash (RHA):

The process of milling paddy rice results in several byproducts, including bran, broken rice, and husk. These byproducts account for about 78-79% of the total weight, with husk making up the remaining 22-21%. Husks are utilized as a fuel source in rice mills to generate steam during the parboiling process. When burned, husks contain approximately 75% organic volatile matter, leading to the production of rice husk ash (RHA). Burning milled paddy yields approximately 220 kg of husk and 55 kg of RHA in a boiler. According to sources [45-48], RHA is composed of roughly 90% $SiO_2$.

## 2.Fabrication methods:

**The AMMC are typically produced through solid-state processing and liquid-state processing methods.**

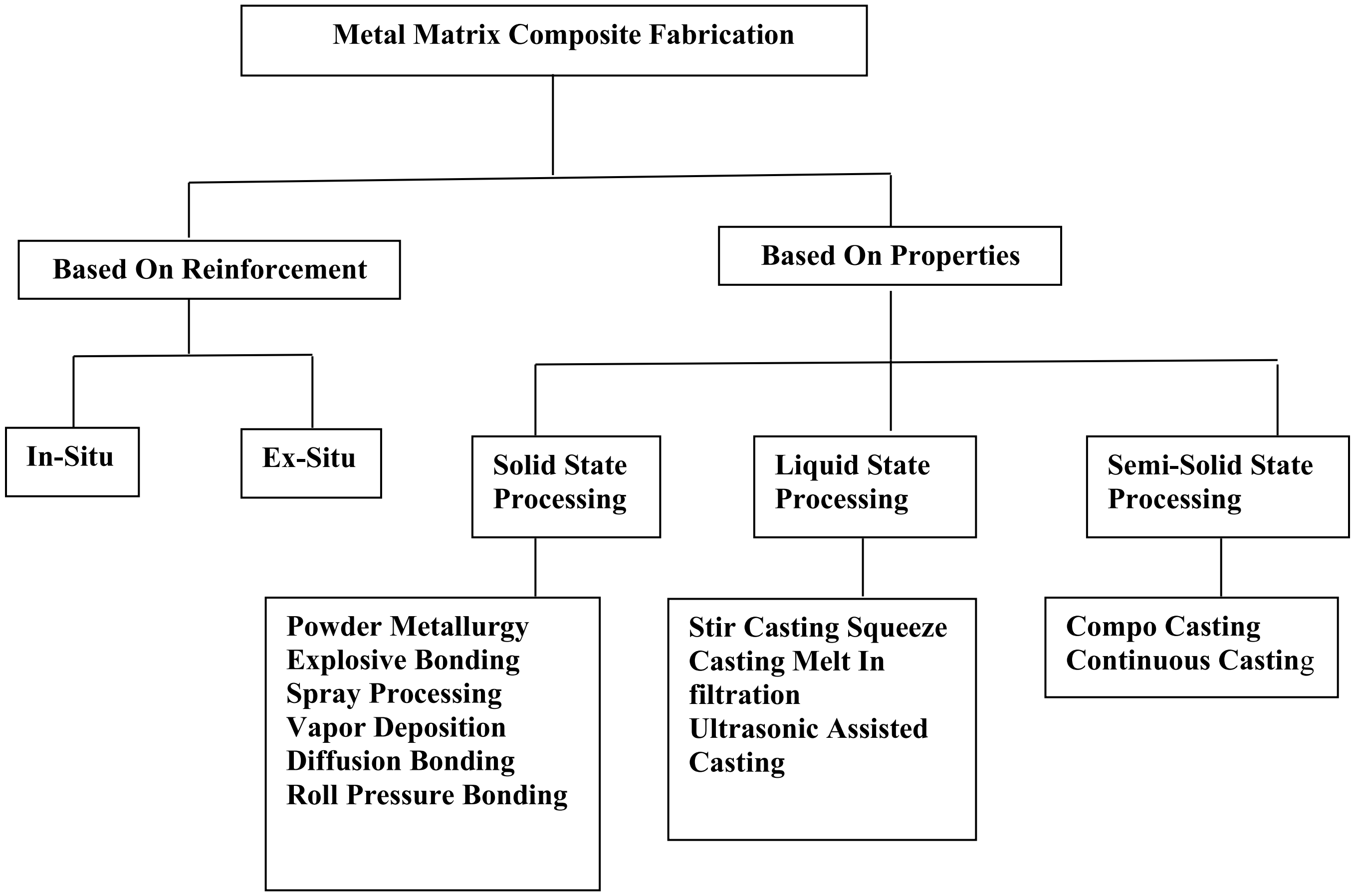



**Fig: 2 Different Metal Matrix Casting Methods**

### 2.1 Solid state processing:

The text encompasses various techniques such as powder metallurgy, ball milling, friction stir processing, diffusion bonding, and vapor deposition. The choice of procedure is contingent upon the type and extent of reinforcement, as well as the desired micro structural characteristics.

### 2.1.1 Powder Metallurgy Process:

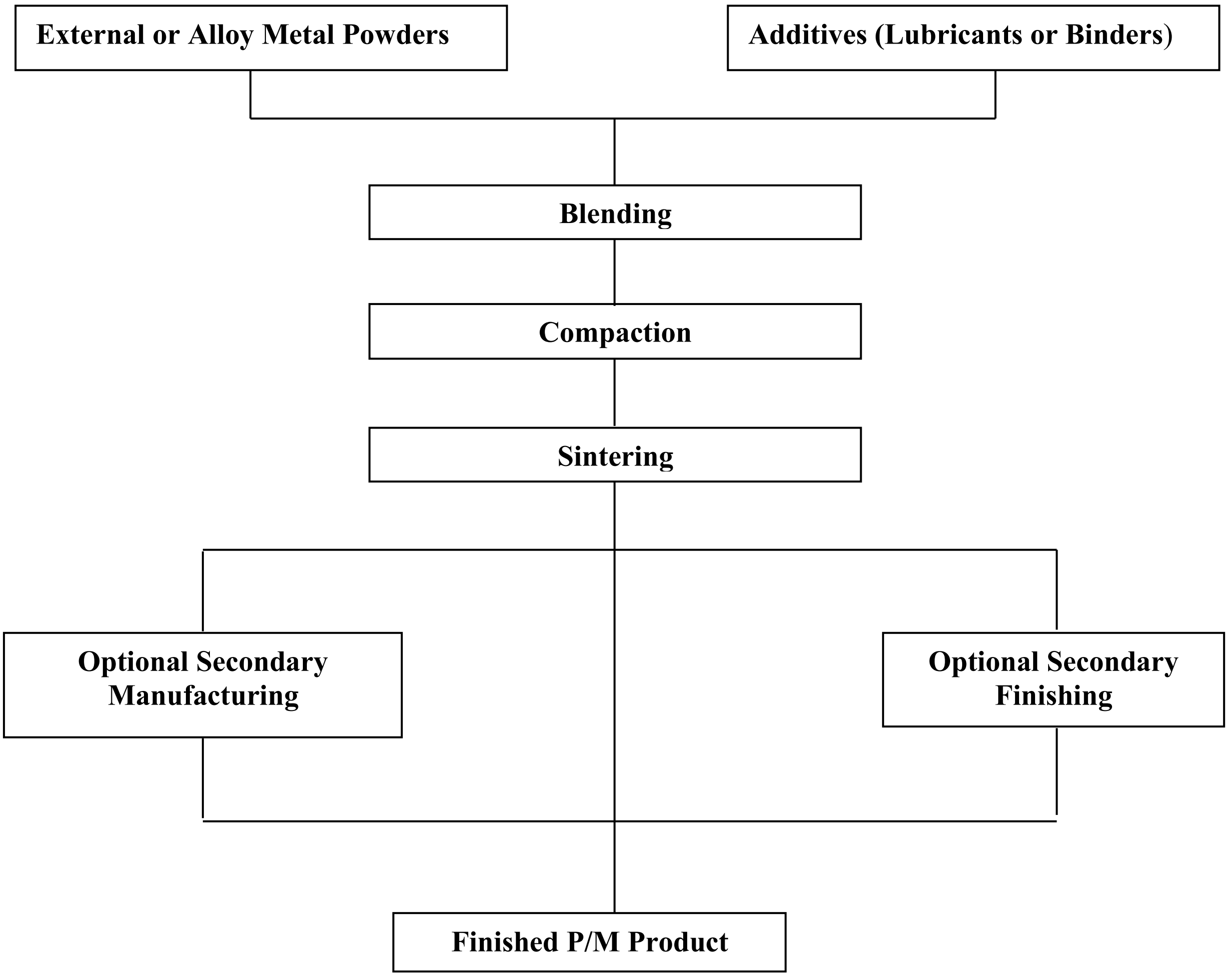



**Fig: 2.1.1. a. Process of Powder Metallurgy**

In this process the metal alloy and reinforcements are uniformly mixed, degassed and sintered under high temperatures. This technique is used to manufacture MMC. In this process primary metal is powdered into small particles and then reinforcements are mixed in powder form in required proportion. Then the mixture is allowed in to mold under high temperature and pressure AMMC are fabricated and investigated [49, 50].

### 2.1.2 Ball Milling Process:

Ball milling, recognized as a mechanical alloying technique, has become a prominent method for producing metal matrix composites [51, 52]. These composites are sophisticated materials that consist of a metal matrix combined with reinforcing phases. The addition of reinforcing agents, such as graphene, into metal matrices can result in substantial improvements in the mechanical, thermal, and tribological characteristics of the composites produced. A key benefit of utilizing ball milling in the development of metal matrix composites is its capacity to ensure a consistent distribution of the reinforcement throughout the matrix. The high-energy milling process is adept at breaking down and evenly dispersing the reinforcing particles, which contributes to a uniform micro structure [53].

### 2.1.3 Diffusion bonding:

This method is frequently used to create MMC with mono filament reinforcing. The inter diffusion of atoms over the metal and reinforcement surfaces is what causes bonding. This technology provides the capability to process a wide range of metal matrices; however, achieving the appropriate dispersion of fibers within the metal matrix presents significant challenges. Furthermore, it is challenging to obtain complicated forms and components using the diffusion bonding process.

### 2.2 Liquid State Processing:

This encompasses methods such as Stir casting, Compo casting, Squeeze casting, spray casting, in-situ (Reactive) processing, and Ultrasonic assisted casting.

### 2.2.1 Friction Stir Processing:

Metal matrix composites have become increasingly popular in the fields of materials science and engineering, thanks to their outstanding mechanical, thermal, and tribological properties. This makes them highly desirable for a wide range of industrial applications. The Stir Casting method has emerged as a favored processing technique for the production of Metal Matrix Composites, attributed to its simplicity, cost-effectiveness, and versatility [54].

The Stir Casting technique involves the insertion of a reinforcing phase, such as ceramic particles or fibers, into a molten metal matrix through mechanical stirring. Through this procedure, the reinforcement can be distributed uniformly throughout the base metal, improving its mechanical qualities and resistance to wear. The successful attainment of the desired microstructure and properties of the final Metal Matrix Composite is contingent upon the meticulous selection of appropriate processing parameters, including stirring speed, temperature, and duration [55, 56].

### 2.2.2 Compo Casting Process:

For low cost discontinuous reinforced MMCs, this approach is used, and is not suited for fabrication of continuous reinforcement of ALMMCs [57].

### 2.2.3 Squeeze Casting Method:

The primary method utilized in the liquid processing is squeeze casting. This technique can enhance the production of aluminum-based composite materials. The benefits of this approach include the elimination of the need for surface pre-treatment for reinforcing materials and the brief contact time between the melt and the reinforcing material at high temperatures due to the high-pressure effect. Direct and indirect squeeze casting are the two different kinds of squeeze casting procedures. Melted metal is injected into casting cavities with minimal turbulence in both types of operations, and it solidifies inside closed dies at extremely high pressures (usually more 100MPa).

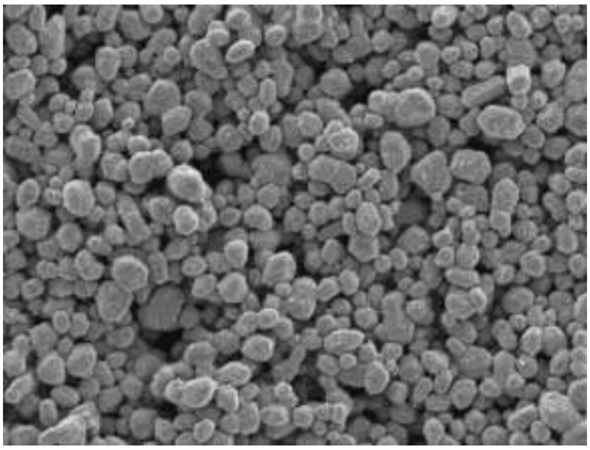
**Material selection**

**1. Matrix Material: Aluminum 7075 Alloy**

**Reason for Selection:**

- High strength-to-weight ratio → suitable for aerospace & automotive parts
- Excellent mechanical properties (high tensile strength, hardness)
- Good fatigue resistance
- Compatible with squeeze casting process

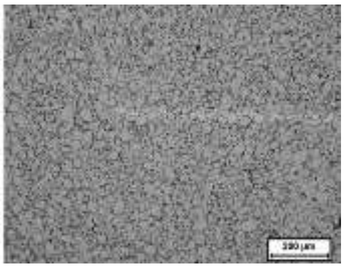
**2. Reinforcement Material: Titanium Carbide (TiC)**



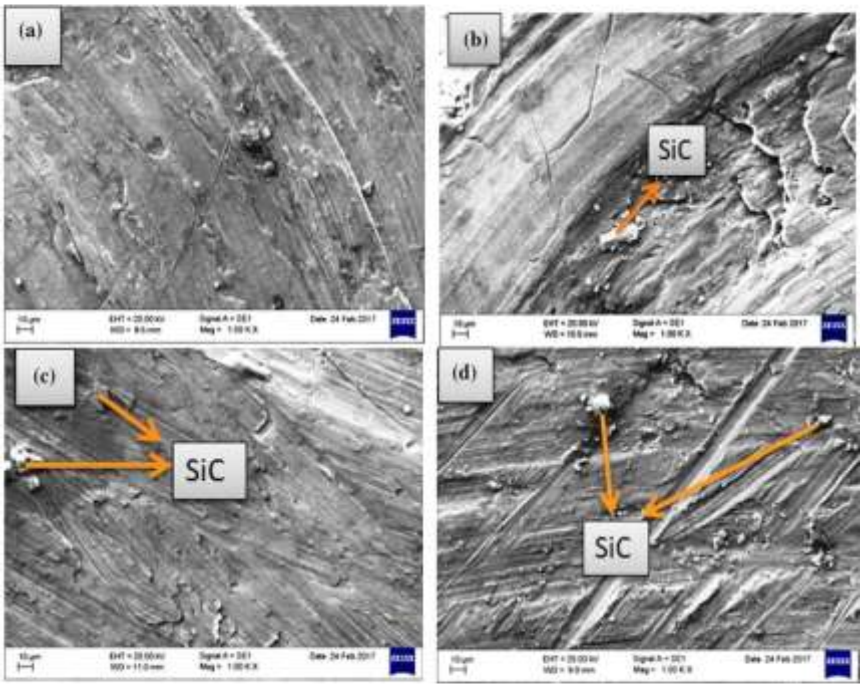
**Reason for Selection:**

- **Very high hardness → improves wear resistance**
- **High thermal stability**
- **Excellent chemical compatibility with aluminum**
- **Enhances strength and stiffness**

## Results and Discussions

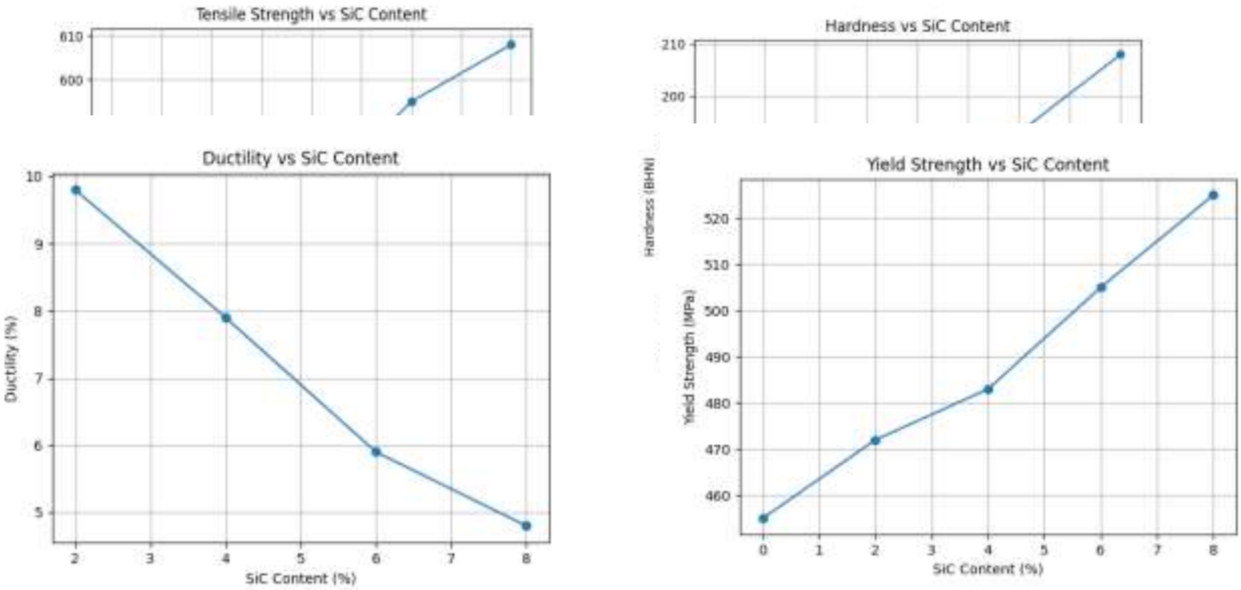


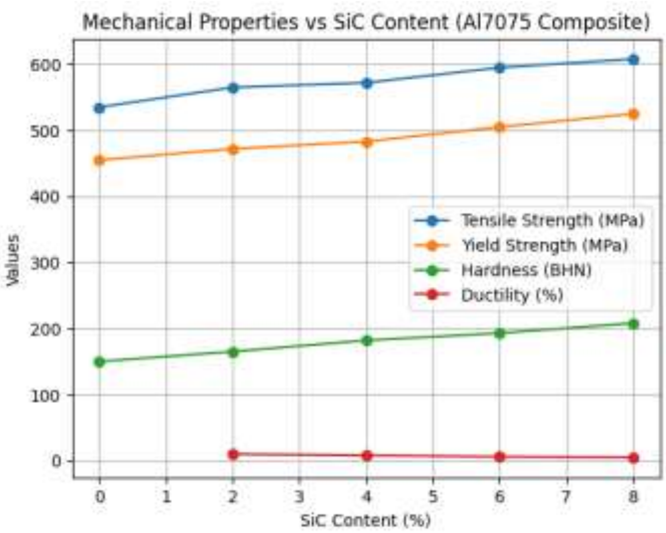
Microscope view Al7075




Overall Comparison of Al7075 alloy with Metal Matrix composites

| Material | Hardness (HV) | Tensile Strength (MPa) | Yield Strength (MPa) | Elongation (%) |
|---|---|---|---|---|
| Al7075 Alloy | 150–175 | 500–570 | 430–480 | 10–12 |
| Al7075+2%TiC | 170 | 602 | 481 | 9.7 |
| Al7075+4%TiC | 196 | 595 | 482 | 9.8 |
| Al7075+6%TiC | 185 | 576 | 485 | 7.1 |
| Al7075+8%TiC | 225 | 618 | 523 | 5.3 |




**Overall Conclusion:**

The addition of SiC reinforcement to Al7075 alloy significantly improves its mechanical properties.
Tensile strength, yield strength, and hardness increase consistently with increasing SiC content due to effective load transfer and resistance to deformation.
However, ductility decreases as SiC percentage increases, making the material more brittle.

**Best Composition for aerospace Industry**

**Most Suitable Composition** : Al7075 + 6% SiC

**Reason:**

**“**Al7075 reinforced with 6% SiC is considered the optimum composition for aerospace applications as it provides a balanced combination of high strength, hardness, and acceptable ductility, ensuring structural reliability without excessive brittleness.”

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