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Effect of Various Filler Materials on Al2195 Alloy by Stir Casting Method-A Review

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ABSTRACT: Aluminium alloys are widely used in aerospace and automobile industries due to their low density and good mechanical properties, better corrosion resistance wear resistance as compared to conventional metal alloys. The fabrication cost also very low for these materials. Stated their qualities they form a very strong conditions in variety of applications. This review paper delves into the alteration of mechanical properties in aluminium metal matrix composites (MMCs) fabricated via the stir casting method. It examines the impact of different reinforcements on properties such as hardness, tensile strength, wear resistance, percentage elongation, and residual stress measurements across various alloys. The study encompasses a range of reinforcements with different weight percentages and particle sizes, as well as variations in process parameters of the stir casting technique.

KEY WORDS: AMMCs, Al2195, stir casting, mechanical properties, tribological .

I. INTRODUCTION

Aluminium matrix composites are valued in aerospace and automobile manufacturing for their numerous benefits. These include a high strength-to-weight ratio, elevated temperature toughness, low density, high stiffness, and superior strength compared to monolithic counterparts. However, the application of this composite class has been impeded by the high cost associated with producing components of intricate shapes [1]. On one hand, there are two primary methods to enhance the thermo-physical properties of Al composites: alloying the metal matrix with metal elements and surface metallization of reinforcements. These two approaches mainly contribute to enhancing the thermo-physical properties of the Al matrix and the interface transmission, while the enhancement of mechanical properties has been seldom discussed [2]. Aluminium-based matrices are recognized as the most economical among other common metallic matrix materials (copper, titanium, magnesium) to produce metal matrix composites (MMCs). Moreover, they can be processed easily using techniques like those employed to produce metals and alloys. The multitude of advantages outlined has propelled Aluminium Matrix Composites (AMCs) to widespread popularity, establishing them as a premier choice material for a broad spectrum of engineering applications. This is owing to their exceptional blend of material properties, ease of processing, cost-effectiveness, and capability to utilize waste materials as reinforcement resources.[3]

Aluminium-Lithium (Al-Li) alloys hold significant appeal for aircraft and aerospace applications due to their exceptional properties, including low density, high stiffness, excellent weldability, and remarkable resistance to fatigue crack growth and corrosion.[4]. The 2195 aluminium alloy boasts appealing mechanical properties, making it a prevalent choice for fabricating external tanks of space shuttles and aircraft skins. Grain structures play a pivotal role in determining the alloy's properties, with dynamically recrystallized grains emerging during the deformation process. These grains persist in subsequent processes, shaping the material's characteristics [5]. The 2195 Al-Li alloy has been utilized by the National Aeronautics and Space Administration (NASA) to fabricate cryogenic propellant tanks for space shuttles. Looking ahead, it holds promise for potential new applications in the realm of aeronautics.[6]

Element	li	Cu	Mg	Ag	Zr	Fe	Si	Ti	Na	Al	H
Content	1	4.02	0.4	0.41	0.11	0.16	0.03	0.068	0.0003	bal	0.017/100gms

Table 1. Al2195 composition [14]

The reinforced material added through stir cast method. Stir casting method is a method which is extensively used for manufacturing the composite materials when compared to the conventional methods. stir casting method is suitable for highly flexible, to improve wear resistance and reduce the rust of the material and we performed several tests on mechanical properties like Tensile, bending, impact and hardness etc. and we collect images of S.E.M& X.R.D images for this process.[7]

Other Reinforcement materials:

TiB₂:

Al-TiB₂ composites with different amounts of reinforcement (3, 6 and 9 wt%) were fabricated using stir casting method. Increasing the volume fraction of TiB₂ reinforcement particles not only enhanced the tensile strength of the composites but also maintained elongation without significant reduction, alongside achieving microstructure uniformity. Increasing the volume fraction of TiB₂ reinforcement particles enhanced the tensile strength of the fabricated composites without any significant reduction in elongation to failure [7].

Graphite:

The particulate reinforcements embedded with AA2218 Aluminium metallic element alloy with 5% constant weight proportion of Graphite with a variable amount of hard reinforcement particulates. The physical and mechanical properties of the Al matrix composite were primarily enhanced, particularly when graphite was used as reinforcement. After aging the graphite-reinforced composite specimens for 8 hours and quenching them with a brine solution, they exhibited higher hardness and reduced wear loss. Consequently, these fabricated reinforcement composites find application in manufacturing sectors requiring additional strength.[9]

TiC:

Aluminium (Al7075) serves as the base matrix metal, while Tungsten Carbide (WC) particulate and Molybdenum Disulphide (MoS₂) act as reinforcements. Fabrication of the metal matrix composites is accomplished via the stir-casting process, with Tungsten Carbide particulate added in proportions of 2%, 4%, 6%, 8%, and 10%. The results revealed that the hardness and tensile strength of the metal matrix composites increased with higher weight percentages of Tungsten Carbide. However, a decreasing trend in hardness was observed at 8% and 10% Tungsten Carbide, possibly due to particle agglomeration resulting from insufficient stirrer rpm. The hardness of the material increased with the weight percentage of Tungsten Carbide up to 6% wt, after which it decreased with further reinforcements. This decline in hardness may be attributed to the agglomeration of the reinforcing particles as the weight percentage of WC increased [11].

B4C:

Al7075 aluminium alloy with reinforcement of B4C and MoS₂ as lubricant under various weight percentages of 4%, 8% and 12% using stir casting process. The friction coefficients of the B4C reinforced composites were maintained in the range of 0.48–0.49 for the applied loads of 10, 20 and 30 N, respectively. The inference drawn suggests that among the two ceramic reinforcement particulates, B4C, being a harder material, primarily contributes to the hardness of the composites, as opposed to MoS₂, which is softer. This substantial contribution has notably increased the hardness of the aluminium hybrid matrix composites. Higher weight percentages of B4C can enhance the hardness, ultimate strength, and yield tensile strength of the hybrid composite due to the presence of harder reinforcement particles. Additionally, the incorporation of the B4C reinforcing element can maximize the friction coefficient [12].

ZrO₂:

The addition of more ZrO₂ resulted in specimens with slightly lower relative density. For the highest porosity (1.44%), the AA6063/1 ZrO₂ composite was selected. Incorporating 1 wt% ZrO₂ increased the hardness of the AA6063 alloy from 66.1 to 74.9. Microstructural analysis of the composite materials revealed ZrO₂ nanoparticles aggregating into larger particles, confirmed by X-ray diffraction testing showing Al, Al-Zr, and ZrO₂ phases. Increasing ZrO₂ content

reduced volume loss under the same load and sliding speeds. At 10 N, abrasion was the predominant wear mechanism, while at 25 N, abrasion and delamination occurred. Wear graphs indicated that surfaces with higher ZrO₂ content exhibited reduced wear and damage [59].

Al₂O₃:

Al5052 alloy serves as the primary material reinforced with zirconium dioxide and aluminium oxide, with the concentration of Al₂O₃ varying from 5wt% to 10wt%. Parametric optimization of wear behaviour was conducted using the Taguchi method with an L9 orthogonal array. Nine specimens were prepared according to ASTM standards using the stir casting technique for wear testing on a pin-on-disc (POD) setup. Design of experiments for wear parameters was analysed via Minitab optimize software. It was observed that the load was the most influential parameter, accounting for 45.12% of the wear behaviour, followed by the weight percentage of reinforcements (29.48%), and sliding speed (25.40%). The combination yielding the least wear rate comprised a 25N load, 300 rpm sliding speed, and 5 wt% of reinforcement [19].

Mg and MgO:

Al-xMg-MgO composites were fabricated using the stir casting method, with varying amounts of Mg (1, 3, and 5 wt%) and MgO (0.5, 1.0, and 1.5 wt%) added to the aluminum matrix at temperatures of 700, 800, and 900 °C. The additions of Mg and MgO improved hardness (72.8 HR-15T) and compression strength (646.4 MPa) through solid solution and dispersion strengthening mechanisms. The highest hardness (72.8) was achieved with 5 wt% Mg and 1.5 wt% MgO (sample A3), while the highest compression strength (646 MPa) was observed at 800 °C with 3 wt% Mg and 0.5 wt% MgO (sample B2), despite its maximum porosity content. ANOVA analysis indicated that casting temperature played the most significant role in compression strength, followed by MgO content and Mg content, respectively. However, variations in Mg content had a greater impact on hardness, density, and porosity values of the composites.[20].

Si₃N₄:

This study focuses on producing aluminium (Al7075) matrix composites reinforced with various weight percentages of and silicon nitride (Si₃N₄) particles using the traditional stir casting technique. Reinforcements were added in increments of 2% from 0 to 10 wt%. The results indicate that the addition of and Si₃N₄ particles significantly enhances the density, hardness, and wear properties compared to the base Al7075 alloy. Specifically: Density increased by 11.44% with the addition of reinforcements. Hardness improved by 206% due to the diffusion of and Si₃N₄ particles in the aluminium matrix. HMMC exhibited a substantial increase in coefficient of friction and wear resistance with increasing loads. Wear resistance increased by 35% with the addition of reinforcements. SEM analysis revealed the even distribution of Si₃N₄ particles throughout the alloy matrix, strengthening the resulting composite.[23].

Red mud:

In the current experimental investigation, aluminium 7075 (Al7075) is reinforced with titanium carbide (TiC) and red mud at weight percentages of 3, 6, 9, and 12 using the stir casting process to produce flat castings. Both the Al/TiC and Al/red mud metal matrix composites (MMCs) exhibit fairly uniform dispersion of reinforcements. XRD analysis confirms the presence of aluminium and TiC in Al/TiC composites and aluminium and iron oxide in Al/red mud composites, indicating the absence of other impurities. The addition of TiC increases the strength of the composites, while red mud decreases it. However, the hardness of the MMCs is increased in both cases. Impact strength and elongation are observed to decrease for both MMCs, whether as-cast or heat-treated.[30].

Cr:

The corrosion properties of chromium (Cr) added to a copper-aluminum-nickel (Cu-Al-Ni) alloy were investigated. Alloy samples were prepared with increasing percentages of Cr (4%, 8%, and 12%) using the powder metallurgical technique, while other alloying elements remained constant. The electrochemical behaviour resembled that of Cu-Ni alloys and pure Cu due to the formation of thin oxide layer films influenced by Cr. The material demonstrated resistance to biofouling due to the presence of Cr. Hardness tests revealed an increase in hardness with Cr additions. Hypothetical and authentic densities of hot forged samples showed a continuous increase with the addition of Cr. Optical microscopy at varying magnifications was utilized to examine the presence of Cr embellishments [31]. Aluminium matrix composites were fabricated using the stir casting method with reinforcement weight fractions of 4%, 8%, and 12% chromium, showing uniform particle distribution. Tensile strength increased from 70 MPa to 79.71 MPa

(a 13.9% increase) with 8% reinforcement, while compression strength rose from 359 MPa to 384 MPa (a 6.96% increase). Hardness increased from 62 BHN to 82.72 BHN with increasing weight percentage of chromium, but began to decrease beyond a certain limit.[33]

Multiwall carbon nanotubes:

AA5083 alloy, widely used in corrosive and cryogenic environments, has garnered attention for its improvement through the addition of Multiwall Carbon Nanotubes (MWCNTs). This study focuses on MWCNTs with over 98% purity, 5–20 nm mean diameter (D), and 1–10 μm average length (L), added to AA5083 in compositions ranging from 1 to 1.75 wt%. The resulting Aluminium Nano Metal Matrix Composite (AMMC) exhibited uniform dispersion and reduced cluster formation of MWCNTs in the matrix, enhancing hardness. Hardness increased from 74 BHN for AA5083 to 84 BHN for the composite with 1.75 wt% MWCNT, with significant improvement observed for compositions of 1, 1.25, and 1.5 wt% MWCNT. Moreover, AA5083/MWCNT composites demonstrated better corrosion resistance in dilute HCl at room temperature compared to AA5083 alloy.

Selected reinforcement materials:**Molybdenum disulfide:**

Molybdenum disulfide (MoS₂) has garnered significant attention in the scientific community due to its layered structure and diverse applications. Being naturally abundant as the mineral molybdenite, MoS₂ is relatively inexpensive and thus holds promise for various fields of research.[8].

Molybdenum disulfide particles exhibit a low coefficient of friction, outstanding catalytic activity, and exceptional physical properties. Additionally, they possess a large active surface area, high reactivity, and increased adsorption capacity compared to bulk material [37]. Joseph conducted a study on the properties of alloy reinforced with molybdenum disulfide (MoS₂) through stir casting. Their findings revealed a significant enhancement in mechanical properties, including hardness and tensile strength. They observed a uniform distribution of reinforcement particles throughout the composite, leading to improved density. Moreover, the incorporation of MoS₂ particles resulted in increased wear resistance and hardness of the composites.[9]. The main purpose of Molybdenum disulphide is to provide lubrication effect at the sliding interface [9]. The inclusion of MoS₂ in the matrix material increases wear resistance by fostering the development of a solid lubricant tribo-layer at the contact sliding surfaces. Various studies have highlighted the impact of MoS₂ particles on the wear behaviour of Al Metal Matrix Composites (AMMCs) as hybrid reinforcements. Upon examination of the tribological properties of Al-MoS₂ hybrid composite, it was observed that the incorporation of MoS₂ particles decreased the rate of wear and friction coefficient [10]. The ultimate tensile strength of composites increased with the addition of the weight percentage of 0 wt % to 4 wt % of MoS₂ and a further increase in wt.% of MoS₂ decrement was noticed [12]. The tensile Strength of 2024 Al with 4% MoS₂ showed highest value. The Hardness was found to be the maximum for 4% MoS₂ composite.[8]. The increased weight percentage of B4C and MoS₂ can enhance the hardness, ultimate strength, and yield tensile strength of the hybrid composite due to the presence of harder reinforcement particles [12]. Molybdenum disulfide (MoS₂) was consistently added to the base alloy in a proportion of 4% based on the mass fraction to the molten metal [11]. Molybdenum disulphide (MoS₂) solid lubricant with an average particle size of 1.5 μm and a density of 4600 kg/mm³ was used as the reinforcement in this investigation [36].

Hastelloy:

The Ni-Cr-Fe-Mo alloy, Hastelloy X, is widely utilized in high-temperature applications demonstrating greater usage at elevated temperatures compared to Inconel 718. Thermal exposure results in the development of molybdenum and chromium-rich carbides. Furthermore, investigations have examined the physical properties of Hastelloy C-276 and the mechanical properties of fully coated buffer layers serving as substrates for semiconductors at low temperatures, indicating the versatility of materials capable of functioning in both high and low-temperature applications.[13]. Hastelloy X is a solid solution strengthened Nickel-based superalloy renowned for its exceptional oxidation resistance and high strength, particularly at elevated temperatures. Its widespread utilization spans across gas turbine engines and the chemical processing industry.[26]. In this thesis, porous Hastelloy-X alloy scaffolds, featuring 80% porosity and currently employed in the production of seals for turbine applications, served as the foundational material. The microstructure of these porous Hastelloy-X scaffolds was infiltrated using a room temperature-curing silicate colloid

(trade name - Dichtol HTWG Hydro #2506) and a novel zirconia-based colloid to produce the metal matrix composites.[27].

element	C	Mg	K	S	Si	Cr	Ni	Mo	Fe	Ti	Al	Co	B	Cu	W
content	0.15	1	0.040	0.030	1	23	bal	10	20	0.15	0.50	2.5	0.01	0.50	1

Table 2. Hastelloy composition [13]

II. METHODOLOGY

Casting:

Casting stands as the primary method widely employed for fabricating metallic components beyond the oral cavity. This age-old and sophisticated metallurgical art form relies on the fundamental principle that 'liquid conforms to the shape of the vessel containing it'. The procedure entails encapsulating a wax pattern within a heat-resistant investment material mould, then eliminating the wax through heating and introducing molten metal into the mould via a channel known as the "sprue." However, during casting, the occurrence of defects is possible. While minor defects can be addressed, major defects can result in increased investment costs.[16]

The composition of aluminium matrix alloys is produced through various techniques, including squeeze casting, liquid metal infiltration, spray deposition, sand casting, investment casting, die casting, permanent mould casting, centrifugal casting, continuous casting, shell moulding, and stir casting. The mechanical properties of the alloy or material are influenced by the casting process.[15].

Types of casting:

Sand casting:

Sand casting is often utilised in industries For Instance: automotive, aerospace and design industries etc... To make parts of comprised of Iron, bronze, brass, and aluminium. The metal of require is gets melted in a furnace at desired temperatures and poured into a mould cavity formed out of sand. This process is preferred because of inexpensive and relatively free of cost. International Journal of Scientific Research in Science, Engineering and Technology (ijrsrset.com) 464 However, flaws are very common in sand cast parts and these affects the properties of castings.[16]



Fig1. Sand casting

Centrifugal casting:

Historically, Centrifugal casting has primarily been utilized for producing cylindrical components. Two fundamental types of centrifugal casting machines exist: horizontal machines rotate along a horizontal axis to produce pipes, tubes, brushes, cylinder sleeves, and other cylindrical and tubular castings, while vertical machines rotate around a vertical axis to fabricate gear blanks, pulleys, sheaves, wheels, impellers, electric motor rotors, valve bodies, and similar components.[17].

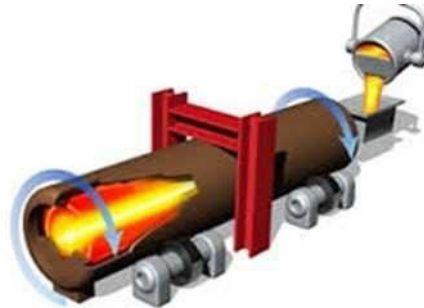


Fig2. Centrifugal casting(17)

Die casting:

Die casting is a metal casting technique wherein molten metal is pushed under high pressure into a mold cavity. This cavity is formed using two robust tool steel dies that are machined into the desired shape, functioning akin to an injection mold during the process. The equipment for casting and the metal dies constitutes significant capital investments, which typically restrict the process to high-volume production. Nonetheless, manufacturing parts through die casting is relatively straight forward.[16]

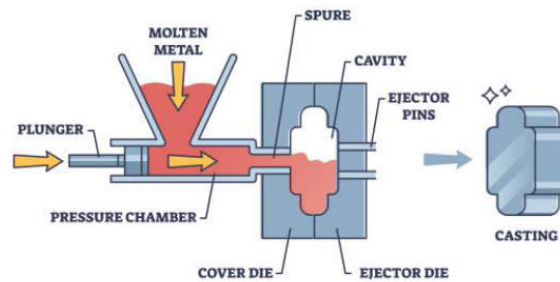


Fig 3. Die casting(16)

Investment casting:

Investment casting is a manufacturing process where a wax pattern is coated with a refractory ceramic material, which, once hardened, takes the shape of the casting's internal geometry. The wax is then melted out, and molten metal is poured into the resulting cavity. After the metal solidifies within the ceramic mold, the metal casting is removed.[16]

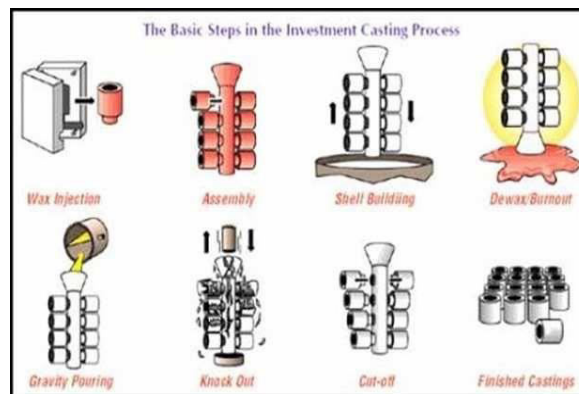


Fig4 . Investment casting(16)

Stir casting:

Several techniques are employed in the manufacture of aluminum matrix composites, including squeeze casting, liquid metal infiltration, spray deposition, and stir casting. Among these methods, stir casting stands out as particularly advantageous due to its simplicity, flexibility, and cost-effectiveness. However, technical challenges persist within stir casting, notably concerning the uniform dispersion of reinforcement, the wettability of reinforcement with the matrix, and the occurrence of porosity.[18]. The preparation of machineries, products, and any shape of items has been carried out using the stir casting procedure. This method is relevant to dimensions and volume of % weight on reinforcements[19]. Metal matrix composites (MMCs) can be manufactured through both solid- and liquid-state processes. Among these, the liquid-state process, regarded as one of the most significant composite production methods, holds particular appeal due to its simplicity, cost-effectiveness, and rapid production capabilities. Typically, this technique is categorized into six main methods: squeeze casting, compo-casting, spray deposition, pressure infiltration, in situ processing, and stir casting [20]. Achieving uniform dispersion of reinforcement particles is crucial for enhancing the mechanical properties of metal composites . The mechanical properties of cast composites are predominantly influenced by the porosity of cast MMCs, which adversely affects corrosion resistance. Therefore, minimizing porosity levels is essential. While complete elimination of porosity is not feasible, it can be controlled. Major reasons for porosity include (a) hydrogen gas evolution, (b) shrinkage phenomenon during solidification, and (c) entrapment of gases during mixing. Porosity levels are mainly influenced by process parameters such as stirrer speed, stirrer position, and holding time [24]

Numerous studies have investigated the production of metal matrix composites via the stir casting process, exploring variations in different process parameters. However, the impact of stirrer rpm and blade angle on achieving uniform dispersion of reinforcement particles in the molten matrix remains unclear.

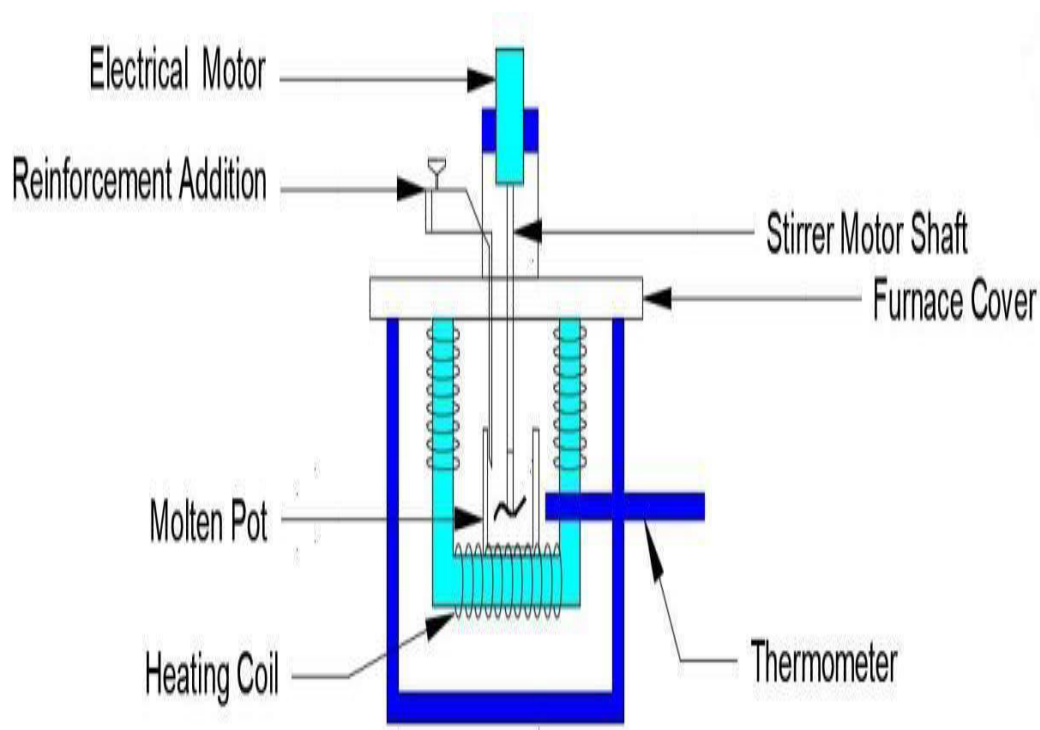


Fig 5. Stir casting process

The series of different activities consisted in stir casting process are depicted in Figure 3.[21]

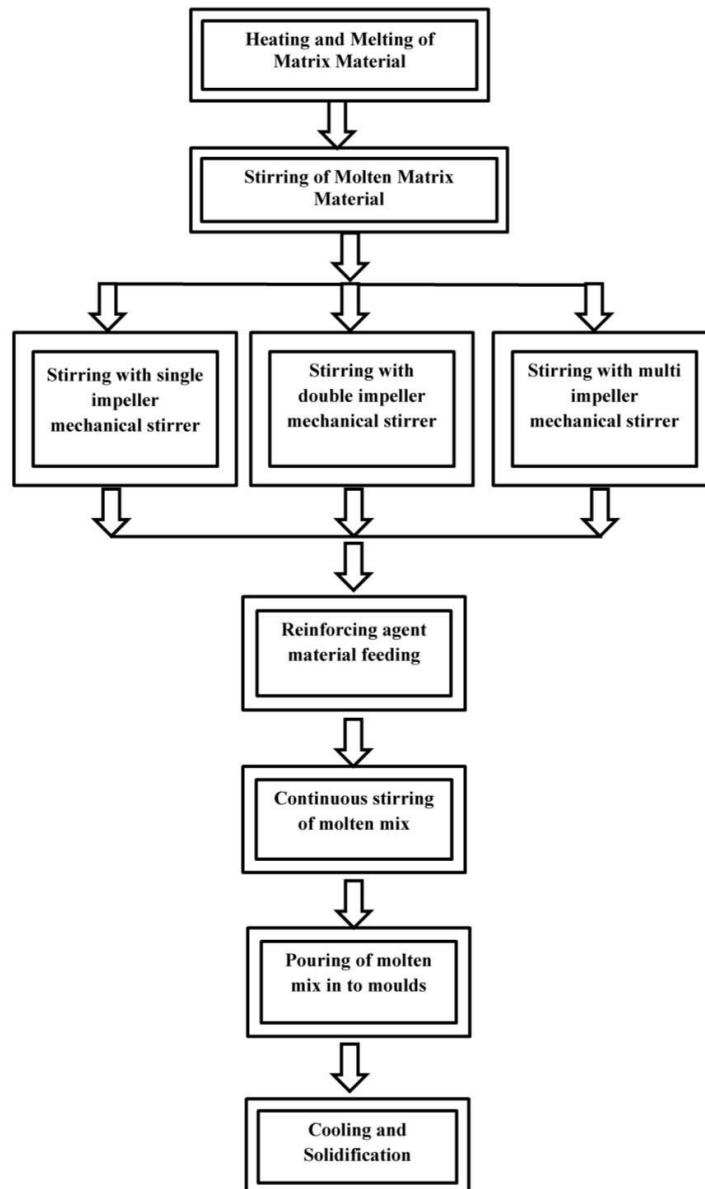


Fig 6. Flow diagram showing the procedure of stir casting technique

Composite preparation:

Hybrid metal matrix composites [HMMC] are fabricated using the traditional Stir Casting Method.[22]. This casting apparatus consisted of different parts including powder injection system, agitator made of titanium, resistant furnace, thermocouples for temperature control, alumina crucible which operates under argon atmosphere.[7]. The liquid-state stir casting method used for fabricating composite materials, the base matrix material is melted inside a crucible at an elevated temperature. Mechanical stirring is then optimized and applied to the melt, ensuring that the reinforcement particles added into the mixture are uniformly dispersed, resulting in the formation of a homogeneous casting.[23]. The melting of the base material is done in furnace by heating. The proper mixing of molten matrix material and reinforcing material is required for generation of isotropic mechanical properties. This mixing is done with a stirrer, equipped with a stirrer rod and blades.[25] Al-2195 matrix was melted in a clay graphite crucible of 5kg capacity using an

electrical furnace at 760 °C, which was above the melting point of the aluminium alloy . A mechanical stirrer with blade angle of 90° from the shaft axis was used for stirring the molten metal during the melting process. When the AA reached to liquidus stage, slag powder was spurted to remove the slag content. Next, the slurry was degassed using Argon gas. The conducted stir casting experiment to know the effect of stirring speed and stirring time on the hardness of casted SiC reinforcing based AMC. They have chosen three different speeds of stirring as 500, 600 and 700 rpm as well as three different time duration of stirring i.e. 5, 10 and 15 min. A mechanical stirring action at a rate of 525 rpm was imposed to the molten matrix and reinforcement mixture in order to obtain a homogeneously dispersed solid solution for a time period of 8 minutes. The molten metal was then poured into mould which is preheated around 100 °C [35]. During the process of degassing, the temperature of the melt was reduced to below the liquidus temperature of 680 °C. When the process terminated, the surface was cleaned again, and the temperature of the melt was increased to 780 °C. At this temperature, preheated SiC microparticles (procured from Sigma-Aldrich) were added to the molten metal at different weight percentages to produce composite materials with varying compositions. Thereafter, the slurry was superheated above the liquidus temperature and automatically stirred at an average speed of 550 rpm for about 10 min. Finally, the molten material was poured using a ladle into pre-heated mild steel disc moulds.

Mechanical properties:

Hardness test:

Hardness is inherent to a material and isn't considered a fundamental physical property. In the Brinell method, a predetermined test load (P) is applied to a carbide ball of constant diameter (D) for a specific duration before removal. Measurements are then taken using a Brinell microscope or optical system, assessing the impression across at least two diameters, typically at right angles to each other, and averaging the results (d).[33]. The literature indicates that hardness tests were conducted in accordance with the E-10 ASTM Standard. The prevailing method involved utilizing a Brinell hardness tester equipped with a standard 2.5mm diameter ball indenter, applying a load ranging from 10 to 35 kg for a duration of 20 to 30 seconds. Brinell hardness number (BHN) readings were captured at various locations on the specimens, allowing for the observation of the relative effects of particle segregation.[28].

The hardness test samples were prepared according to the standards, with dimensions of 15 mm * 15 mm * 6 mm, meticulously polished to achieve a smooth and uniform surface. Micro-hardness was assessed utilizing a Vickers hardness tester (HM113 by MITUTOYO, Japan) equipped with a diamond indenter.[29]. The micro-hardness of the MMCs is evaluated using an OMNITECH semi-automatic Vickers hardness testing machine, applying a load and dwell time of 500 g and 10 s, respectively. Hardness measurements are conducted at five distinct locations across the specimen's surface, with the average value being calculated to mitigate the influence of particle agglomeration.[30] The hardness of the base metal and composites was evaluated using Vickers hardness testing machine at 1 Kg load for a dwell period of 10 s. Around 15 readings were taken for every sample.[32]

Rockwell hardness tester is used for evaluating the hardness of the fabricated specimens [22]. The Rockwell hardness assessed using a B-scale indenter with a 100 kgf load and a 1/16-inch steel ball indenter. The results indicate significantly higher hardness values compared to those observed for existing NAB alloys.[31] Hardness and compression tests were conducted on the specimens to determine the mechanical properties. Hardness tests were carried out by using Matsuzawa dxt-3 universal hardness tester. The hardness values of the composites were 265 measured with the Rockwell 15T hardness method according to ASTM E18-15 standards [29]. Bulk hardness measurements were carried out on the base metal and composite samples by using standard Rockwell hardness test machine. Rockwell hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness. Load applied was 100 kg and indenter used was 1/16"[34].

Tensile test:

The specimens were machined to get dog boned structure as per ASTM E-8 standards.[34]. The tests revealed that, the ultimate tensile strength gradually increased by the increase in wt. % of the reinforcement added to the metal matrix. The maximum Tensile strength was observed at 4% MoS₂[34]. Tensile testing was performed utilizing a Hounsfield tensimeter, and the ultimate tensile strength of the specimens was determined by assessing the load at which fracture occurred.[36]. The tensile test has been done with dog boned structure-based specimens using computerized UTM TUE-C-600 Model Machine as per ASTM E 8 standards.[38]. Tensile, Corrosion, EDAX and Microstructure test samples were prepared by electric discharge machining process.[39]. Tensile testing was carried out at room

temperature at a strain rate of s^{-1} using an Instron universal testing machine. The tensile properties for each condition, namely the yield stress (YS) at a 0.2% offset strain, ultimate tensile strength (UTS) and fracture elongation (%El), are reported as an average value of six test samples. [29]. The tensile and bending tests were conducted on the prepared specimens in accordance with ASTM E8 and E9 [11] standards, utilizing a universal testing machine at room temperature. These tests aimed to investigate properties such as ultimate tensile strength (UTS), yield strength, percent elongation, and bending strength. The tensile test specimens had a length of 104 mm, a holding diameter of 12 mm, a gauge length of 45 mm, and a diameter of 9 mm. [40]. The specimen for the tensile test is flat in shape. The size of the samples was prepared as per ASTM E8M04 standard which is shown in fig After 5mm thickness was removed from the edge of castings, 2.5 mm thickness was removed from middle portion and then 12 mm thickness was removed according to the shape of test specimen which is shown in. One sample from each castings (two samples of each alloy) was prepared which is shown in Fig.[39].

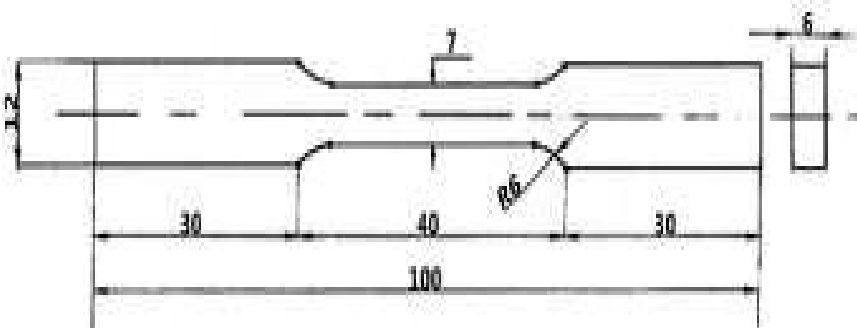


Fig 7 Dimensions of tensile specimen[39].

Charpy impact test:

Charpy impact test specimen of 55 mm x 10 mm x 6 mm cross-section with 45° V-notch at the centre are prepared as per ASTM E23 standards. The specimens with the required dimensions are cut using a wire cut EDM process. Charpy impact test is conducted using a 200 J capacity standard pendulum type impact testing machine. [30]. Charpy V-notch tests were very practical experiments to determine the relative energy absorption capability of the materials. Within the study, Charpy V-notch tests were carried out to determine the fracture toughness of the selected Al alloys. The experiments were conducted only at room temperature. Three individual V-notched test specimens having a length of 55 mm, 8 mm ligament length, and 45° angles of the notch were prepared, The V-notched specimens were machined from the stock [41].

Bending test:

In addition, bending strength of composites was evaluated by three-point bending tests.[7]. A total of 17 CHS specimens, extruded from a 6082-T6 aluminum alloy, underwent four-point bending tests. A pure bending region was achieved between the loading points, with key design parameters being the diameter-to-thickness ratio (D/t) and slenderness ratio. Five section dimensions (89 mm × 4 mm, 89 mm × 5 mm, 114 mm × 4 mm, 114 mm × 5.5 mm, and 114 mm × 7 mm) were utilized for the tested CHS beams, with D/t values ranging from 16.4 to 29.1. Two actual lengths (La) of 2400 mm and 2000 mm were chosen for each cross-section, resulting in varying slenderness ratios (λ) from 46.1 to 76.1. Most of the tested beams underwent one or two repeated tests to validate the experimental results. All specimens were simply supported, with both ends extending 100 mm beyond the centrelines of the supports, effectively reducing the effective lengths (Le) to 2200 and 1800 mm. [55]

Tribological properties:

Corrosion test:

Potentiodynamic polarization electrochemical method:

The corrosion behaviour of the composites was analysed in a 3.5% NaCl solution at room temperature (25°C) through potentiodynamic polarization electrochemical techniques. Prior to testing, the surfaces of the samples were wet ground with silicon carbide papers from 220 down to 600 grade in accordance with ASTM standard. Afterwards, the samples were washed with distilled water, degreased with acetone and dried in air [45]. The corrosion studies were conducted

using a Princeton Applied Research Potentiostat (Versa STAT 400) with versa STUDIO electrochemical software. A three-electrode corrosion cell setup was employed, with the sample serving as the working electrode, saturated silver/silver chloride as the reference electrode, and platinum as the counter electrode [3]. The working electrode surface underwent polarization from -250 mV to +250 mV concerning the Open Circuit Potential (OCP) at a scan rate of 0.25 mV/s. Prior to each experiment, the OCP was allowed to stabilize for 30 minutes.[1]. The polarization curve was examined using the Tafel extrapolation method. Electrochemical impedance spectroscopy was conducted across a frequency span ranging from 100 kHz to 0.01 Hz, employing an AC voltage amplitude of 5 mV. Ten data points were collected for each order of magnitude during the experiment.[40]. The specimens are submerged in test solutions for a minimum of 30 minutes to attain a steady-state potential. Potentiodynamic current curves are then recorded for polarizing test specimens at ± 250 mV, both cathodically and anodically. These tests are conducted at a sweep rate of 0.167 mV/s. The potentiostat variables (I_{corr} : corrosion current in A/cm², and E_{corr} : corrosion potential) are documented to align with slopes derived from polarization curves obtained through potentiostatic measurements.[44]. After each experiment, the electrolyte was replaced, while the test samples were polished, rinsed in water and washed with acetone to remove the products that might have formed on the surface which could affect the measurement. Three repeat tests were performed for each grade of composite produced to guarantee reproducibility and repeatability of test results that were observed to be good as there were no significant differences between results from triplicates.[45].

Immersion test:

The immersion corrosion test was conducted following ASTM G31 standards. Specimens measuring 15x15x6 mm³ were polished using 1200 mesh emery paper, weighed, and then submerged in aerated 1 N NaCl solution at room temperature for durations ranging from 24 to 120 hours, incremented by 24-hour intervals. At the conclusion of each time interval, the specimens were cleaned with acetone in an ultrasonic bath and weighed again [51]. were immersed in 3.5 wt.% NaCl solution at room temperature for the following times: 1 minute, 5 minutes, 10 minutes, 20 minutes, 30 minutes, 50 minutes, 3 hours, 6 hours, 15 hours, 40 hours, and 72 hours. Only the results obtained for the samples immersed for 1 minute, 30 minutes, 3 hours, 6 hours, 15 hours, 40 hours, and 72 hours are presented. After immersion, the sample was washed, dried, and promptly analysed using CLSM (Olympus OLS4100). The corrosion evolution was tracked by observing the same microstructure region over time, guided by hardness impressions.[53]. The alloy specimens (35 mm × 35 mm × 4 mm) underwent immersion corrosion in 3.5% NaCl solution for 20 days. Prior to immersion, specimens were polished and cleaned with acetone and water. After the test, chromic-phosphoric acid was used to remove corrosion products following ASTM G1. Surface morphology was analysed using stereo microscopy and optical profilometry (NANOVEA, USA), with parameters like average pit depth and pit density compared between the alloys using Mountain software [54]. The corrosion rate is calculated by below formulae.

$$\text{Corrosion rate} = K \times W / (A \times T \times D)$$

Where,

K=87600 mm/yr (const)

W=Weight loss in grams

A=Area in Cm³

T=Time of exposure in hours

D=Density in gm/cc

The sample surface was polished, degreased with acetone, cleaned, and dried before weighing using a SHIMADZU-AUY220 electronic balance to measure its initial surface area. Subsequently, the sample was immersed in a 1 mol/L NaCl + 1 mol/L NaHSO₃ etching solution for 192 hours, undergoing cleaning and drying every 48 hours before reweighing [50].

Wear test:

The tribological investigation is the discipline of interacting surfaces under relative motion. Tribological behaviour revealed that direct relation with the load gives wear rate (WR) and coefficient of friction (COF), while inverse relation with the sliding speed (SS) and sliding distance (SD)[28]. The pin-on-disc device is utilized to assess the tribological characteristics of coatings, including frictional coefficient and wear rate. The coated specimen is positioned on a rotating disc under a variable angular speed controlled by a spring [9]. Dry-sliding wear tests were conducted according to ASTM G-99 using a pin on a disc apparatus under an applied load of 50 N for a sliding speed of 5 m/s.[10]. Before testing, both the pins and the surface of the disc were cleaned using acetone. The tests were carried out using a counter disc made of EN31 steel, maintaining a constant speed of 500 rpm, a sliding speed of 2.61 m/s, and a sliding distance of

2000 mm. Various loads ranging from 5 N to 15 N were applied during the experiments [15]. To attain identical surface roughness conditions, samples were polished with different grades of emery papers and acetone prior to each test. The disc and pin surfaces are washed with an acetone solution [22]. As stress increased, matrix roughness changed, and reinforcement particles contacted pin and counter faces. With longer sliding distances, particles crushed, forming a protective layer, reducing wear in hybrid aluminium composites. Composite hardness increased due to stiffer reinforcement and self-lubricating MoS₂ particles under higher loads [38]. To avoid the influence of uneven structure on the test results, the samples were taken from the centre of the thickness of the plate, as shown in figure. The weight of samples before and after the wear test was calculated to estimate the wear rate [41]. The main purpose of this study is to observe the less wear and hence the objective function for the response was chosen as 'smaller the better' and the values of signal to noise ratio (S/N) values was inferred corresponding to the objective function [43].

Microstructure evolution:**SEM:**

The microstructure of a material significantly influences the performance of composites, impacting physical properties such as robustness, endurance, compliance, stiffness, wear, and corrosion resistance [11]. Morphology of Al matrix composite surfaces was seen by scanning electron microscopy (SEM). The composite surface of ruptured samples results shows no segregation of reinforced particles since mixture was uniform [28]. Scanning Electron Microscope (SEM) were used for metallographic examinations of the composites. The equipment FEI Quanta 250 SEM, equipped with EDAX was utilized for the examination of composite's microstructure [12]. The samples for microstructure analysis were prepared using a double disc grinding machine. Subsequently, they were polished successively with 120, 220, 400, 600, and 800 grit size emery papers. Finally, alumina paste was applied to refine the samples on velvet paper. Following this preparation, all samples were etched using Keller's reagent in accordance with ASTM E407 standards [24]. This reagent has 2.5 mL HNO₃, 1.0 mL HF, 1.5 mL HCl and 95 mL water is extensively used for Al and its alloys for investigation. The composite's grain size is fixed with the 'linear intercept method' using Image software [12].

XRD:

The XRD technique is one of the important phase analysis method performed in the MMC to determine the reaction between the alloy and ceramic components [58]. XRD (X-ray diffractometer Rigaku Miniflex II) was used to find out the phases formed in all the compositions. Cu K-alpha radiation has been used with wavelength of 1.541836 Å and Ni filter [32]. The samples for microstructure analysis were prepared using a double disc grinding machine. Subsequently, they were polished successively with 120, 220, 400, 600, and 800 grit size emery papers. Finally, alumina paste was applied to refine the samples on velvet paper. Following this preparation, all samples were etched using Keller's reagent in accordance with ASTM E407 standards [24]. The presence of these hard phases (Al₂O₃, CaCO₃ and Cr) in the composite was responsible for enhancing the tensile strength, hardness and compressive strength of composite material. However, the presence of Cr is also beneficial to improve the corrosion resistance of composite material [56]. The composite samples underwent phase analyses utilizing a Bruker D8 X-ray diffractometer (XRD) equipped with Cu K_α radiation. Characterization of the as-fabricated composites' microstructure was performed using a Quanta 200 scanning electron microscope (SEM) and High-Resolution Transmission Electron Microscopy (HRTEM, G2 F20) incorporating an energy dispersive spectrometer (EDS). Nanoindentation measurements were conducted employing an Hysitron TI-950 nano-indenter in displacement-controlled mode, maintaining a nominally constant strain rate of 0.05 s⁻¹ [57].

III. CONCLUSION

1. The recent study on composite material manufacturing concludes that stir casting stands out as the most effective and efficient method across various conditions including cost, simplicity of operation, and distribution of reinforced particles.
2. The detailed literature reveals a predominant focus on studying various mechanical properties such as tensile strength, compression strength, impact strength, hardness, and yield strength and tribological properties such as wear rate, corrosion rate of reinforced Al2195 alloy matrix composites, all of which exhibited significant enhancements.
3. From the above literature review conclude that the addition of Molybdenum disulfide to the metal matrix which increases their properties at the weight percentage of 4%. And also conclude that the addition of Hastelloy to metal matrix which increases their properties at the weight percentage of 1%.

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