Forging the Future: Exploring Aluminium AA-6061 Composites through Stir Casting for Advanced Applications and Future Innovations

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Forging the Future: Exploring Aluminium AA-6061Composites through Stir Casting for Advanced Applications and Future Innovations

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Abstract: Aluminum AA6061 alloy composites are known for their improved functionality and material properties in comparison to the basic alloy. The present study reviews the AA-6061 metal matrix composite (MMC) manufacturing process and characterization using the conventional stir casting method. The most typical reinforcements used in the production of AA6061 metal matrix nanocomposites (MMNC) are oxides (Al_2O_3, TiO_2, SiO_2, ZrO_2 and ZnO), nitrides (TiN, BN, Si_3N_4), carbides (B_4C, SiC, TiC, TiB_2, Nb_2Sn, Si_2N_4), carbon nano-tubes (CNTs), Graphene Nano-Platelets (GNPs). Hybrid composites, consisting of two or more reinforcements, have been reported to exhibit relatively superior properties than single-component composites; however, other suitable reinforcements, such as hybrid, inorganic, nanomaterials, and organic reinforcements, are also being explored in current trends. There is a huge scope for research on AA6061 nanocomposites that have much higher strength and wear resistance, making them useful for aerospace and defense applications. Overall, this study highlights the importance of manufacturing and characterizing AA6061 composites and suggests potential areas for future research and development in this field.

Keywords: Aluminium metal matrix; fabrication; hybrid composites; matrix; mechanical properties; reinforcement; stir casting method

1. Introduction

Stir casting is a liquid-state processing technique used in various industries to produce metal matrix composites (MMCs). The method involves mechanically stirring reinforcing materials, such as ceramic particles into a molten metal matrix to enhance its mechanical properties, including strength, stiffness, wear resistance, and thermal conductivity. During the process, solid metal, typically aluminum, is melted in an electric furnace held in a refractory crucible[1)]. To avoid the trapping of reactive gases, the reinforcing materials are heated up and added to the molten metal while the mixture is maintained in an inert environment. Mechanical stirring of the mixture is achieved using propeller blades connected to an electric motor, and the rotational speed is precisely controlled using a stepper motor[2)].

The resulting mixture is then poured into a mold and allowed to solidify, producing an MMC with improved mechanical properties. Stir casting is a cost-effective method that reduces porosity and produces a uniform distribution of the reinforcing particles, making it suitable for producing complex shapes with improved performance characteristics. A setup of stir casting for aluminum alloy AA 6061 MMC is present in the given Figure 1.

Currently, there is a growing demand for Aluminum Matrix Composites (MMCs) in various industrial sectors due to their superior mechanical properties[3)]. The utilization of composites in the production of aircraft and space vehicles is driven by their ability to offer greater strength while reducing overall weight. Metal matrix composites, ceramic matrix composites, and polymer matrix composites are the three groups into which aluminum composites may be divided. Metal matrix composites (MMCs) made of aluminum are among them, and because of their remarkable qualities, they are often used in a variety of automotive applications[4)].

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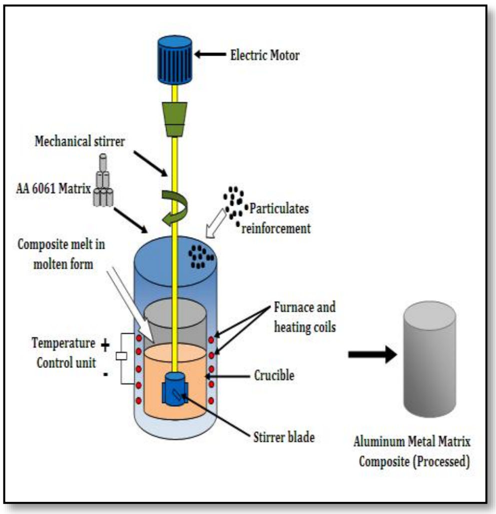

Fig.1: A setup of Stir Casting

Aluminum Matrix Composites (MMCs) consist of at least two components: a pure alloy (matrix) and a reinforcement material[5]. AA 6XXX aluminum alloys are utilized in manufacturing aircraft body parts and IC engines, with Silicon (Si) and Magnesium (Mg) being the primary alloying elements. The stir-casting process offers an efficient and economical means of producing AA 6061 composites. Zinc, Chromium, Magnesium, Iron, Copper, Titanium, and Manganese are the primary alloying ingredients for AA 6061 alloy[6].Aluminum matrix composites are highly sought after for their valuable role in diverse engineering applications, primarily due to their remarkable strength-to-weight ratio[7-8]. Modern materials with important engineering uses include AA alloy composites, which are recognized for their low weight, good stiffness, high corrosion resistance, high specific modulus, and outstanding wear resistance qualities.[8]. These composites offer improved mechanical properties and excellent machinability. MMCs have been created using a variety of production processes, including powder metallurgy, stir casting, perform infiltration, mechanical alloying, and spray deposition[9]. By introducing compounds such as Al_2O_3, BN, Si_3N_4, ZrO_2, SiC, B_4C, and TiC, the mechanical properties of the AA 6061 matrix can be augmented, leading to an improvement in its elastic strength, which typically ranges between 70 to 80 MPa[10]. AA 6061 is highly renowned as one of the most widely used alloys in the 6XXX series. It serves as the matrix material in numerous Advanced Metal Composites (MMCs) and has the benefit of allowing for the modification of composite strength via appropriate heat treatment. Numerous sectors, including aviation, automotive, industrial, and the military, have given the creation of composite materials with improved properties a lot of attention. These composites are highly sought-after on the market because they stand out from their underlying basic materials in terms of unique qualities and quality[11-12].

The AA 6061 alloy, part of the aluminum 6XXX alloy series, is known for its exceptional versatility. Stir casting is widely employed to produce composites using AA 6061. Despite numerous studies on AA 6061 composites and their manufacturing processes, a comprehensive review focusing specifically on AA 6061 stir-cast composites is currently lacking. This paper's main objective is to address this gap by providing an extensive review of the various Metal matrix composites (MMCs) made of AA 6061 as the matrix material was produced using stir casting. The authors want to analyze the impacts of various reinforcements in the AA 6061 matrix and determine if stir casting is appropriate and practical for these materials.

2. Matrix and Reinforcement

In the case of AA6061 aluminum alloy fabricated by stir casting, the matrix material is the AA6061 alloy itself. The reinforcement material can vary, but commonly used reinforcements in stir casting for AA6061 include silicon carbide (SiC), alumina (Al_2O_3), graphite, and boron nitride (BN). These reinforcements are typically added to enhance the mechanical properties and performance of the aluminum matrix composite[13]. The combination of matrix and reinforcements in composite production offers a notable advantage, as it allows for the synthesis of high-strength materials while preserving the excellent ductility and density typically found in alloys[14]. It is feasible to remedy any issues with the matrix materials by adding high-strength particles as reinforcements[15]. According to reports, adding reinforcements to an aluminum matrix improves the composite's tensile strength, compressive strength, impact strength, and hardness. Moreover, the wear resistance of these composites is generally higher compared to unreinforced aluminum or aluminum alloys[16]. Various types of materials are utilized as reinforcements in the manufacturing process of AMMCs (Advanced Matrix Composites). Particles, whiskers, short fibers, and laminated, and continuous fibers are some examples of these reinforcements. Excellent isentropic qualities in particular are shown by particle reinforcements, enabling them to disperse uniformly within the matrix phase[17]. The different reinforcement methods are shown in Figure 2.

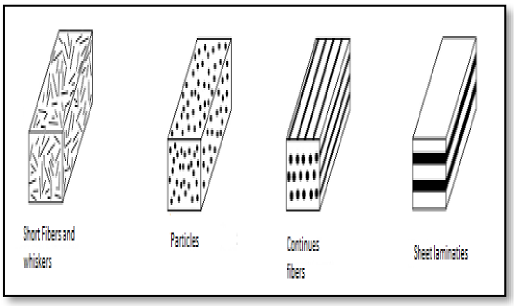

Fig.2: Various forms of Reinforcement

3. Fabrication techniques for aluminum matrix composites (AA-6061)

The main challenge in processing composites is to achieve a homogeneous distribution of the reinforcement phases, which is crucial for obtaining a sound microstructure. The composite can contain reinforcing phases in the form of either particles or fibers, depending on the desired properties and application[18)]. The manufacturing processes for aluminum matrix composites (AMC) on an industrial scale can be classified into the following groups[19)]. The given Table 1 are illustrating a comparative assessment of different fabrication techniques.

Liquid state processes comprise various methods such as stir casting, ultrasonic-assisted casting, spray casting, squeeze casting, in situ (reactive) processing, pressure less infiltration, vacuum infiltration, and dispersion methods. Powder Metallurgy Processing, stir process, diffusion bonding, Microwave sintering, Vacuum sintering, high energy ball milling friction, and procedures for vapor deposition are examples of solid-state processes. In situ, reaction, Compo casting, and Rheocasting are examples of Semi-solid fabrication Processes of AMMCs. In the Given Figure 3 are illustrate the different fabrication processes of AMMCs.

Table 1: A comparative assessment of different techniques [20)]

Method	Range of Vol. fraction	Range of Shape and Size	Damage to reinforcement	Cost
Stir Casting	Up to 0.3	Wide range of shapes, larger sizes up to 500 kg	No damage	Least Expensive
Spray casting	0.3-0.7	Limited shape, large shape	Mitigate damage	Expensive
Powder Metallurgy	0.4 to 0.95	Wide range, restricted size	Reinforcement fracture	Expensive
The Squeeze Casting	Up to 0.5	confined by physical form 2 cm maximum height	Severe damage	Moderate Expensive

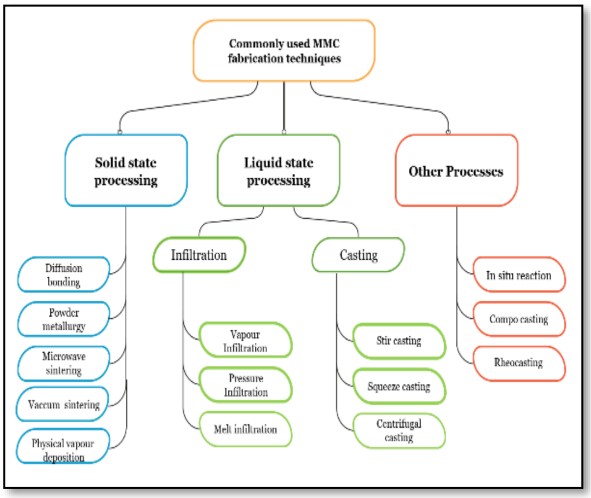

Fig.3: Different kinds of fabrication techniques for MMCs

Among the available manufacturing techniques for MMCs, stir casting is one of the least expensive processes. In addition to its low cost, stir casting offers a variety of material and processing conditions and can produce composites with up to 30Wt% volume fraction of reinforcement for better bonding because this increases contact points between the phases, and allows for effective matrix penetration, resulting in improved load transfer and overall composite performance or metal matrix with reinforcement particles due to the stirring action[20-23)]. The economic viability and versatility of the stir-casting process have made it a favored choice for large-scale fabrication. By utilizing this method, it becomes possible to create complex profiled Metal Matrix Composites (MMCs) without causing any detrimental effects to the reinforcement particles[24)]

4. Parameter Study of Stir Casting

4.1. Study of various parameters that affect mechanical properties of stir-casted AMMCs:

The properties of MMCs (Aluminum Matrix Composites) are greatly affected by the parameters involved in the stir-casting process. Among these parameters, the size of the reinforcement, holding temperature, stirrer speed, size of stirrer blade, holding time, stirrer time, and melt temperature have the most significant impact. The good news is that these parameters can be easily modified without incurring extra effort or expenses throughout the process. As a result, the selection of appropriate process variables becomes crucial in achieving desired outcomes for MMCs[25)]. The parameters for the fabrication of MMCs by stir casting as shown in Figure 4.

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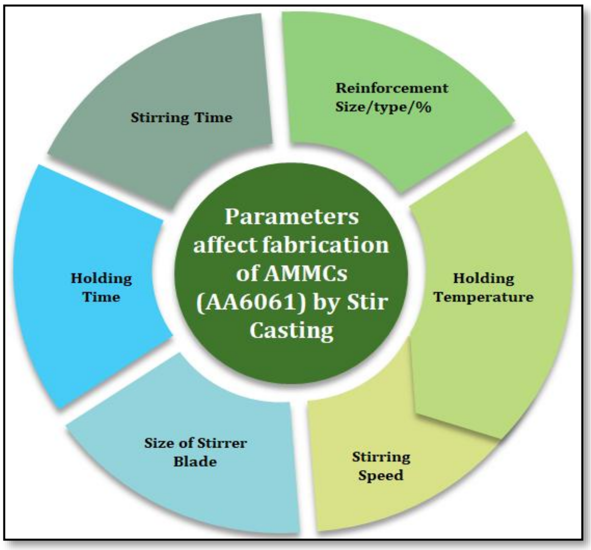

Fig.4: Parameters for fabrication of MMCs by stir casting

4.1.1. Reinforcement Size/type

The mechanical properties of stir-casting materials are significantly affected by the size of the reinforcement. Generally, Composites with fewer reinforcements often exhibit superior strength properties. The stir-casting technique was used to create AZ91D alloy-SiC AMC (aluminum matrix composites) in a work by Palash Poddar et al.[26] Two distinct average particle sizes, 15 µm and 150 µm, and SiC reinforcements with a volume proportion of 15Wt% made up the composites. With the addition of reinforcements, the average grain size shrank. More specifically, composites with 15 µm particles had much smaller grain sizes than those with 150 µm particles. When using finer particles, the grain size refinement was more obvious. Stir casting was used to create aluminum alloy-SiC composites in a work by Yehia M. Youssef et al. They utilized SiC particles of different sizes, specifically 115 µm, 225 µm, and 350 µm, and incorporated weight fractions of 3Wt%, 5Wt%, and 9Wt% of SiC as reinforcements in the matrix. Upon analyzing the materials, it was found that the composite with the smallest SiC particles (115 µm) and a weight fraction of 9Wt% exhibited the greatest improvement in mechanical properties. This indicates that adding finer reinforcement particles leads to the maximum strengthening effect.

4.1.2. Size of stirrer Blade

The stirrer's design is essential because it must successfully generate a forced vortex flow using its propeller blades. To achieve the homogeneous dispersion of reinforcement particles inside the molten fluid, this is crucial. Due to its capability to stop reactions between stainless steel and aluminum alloys at high temperatures, zirconia is commonly used as a protective coating for stainless steel stirrer blades. Therefore, it is highly advised to use a zirconia coating while doing stir casting of AA 6061 MMCs (Aluminium Alloy 6061 Metal Matrix Composites). In addition, the design of the impeller should facilitate the formation of a vortex to ensure thorough mixing of the molten material[27].

4.1.3. Holding Temperature and Melting Temperature

Achieving the appropriate preheat temperature for ceramic reinforcements in stir-casting processes of MMCs (Aluminum Matrix Composites) can be challenging due to their low wettability. However, heating the reinforcements at a temperature of 500°C for 40 minutes can be beneficial. This preheating process aids in the removal of moisture and gases present in the embedded particle[28-29]. In a study conducted by Samuel et al. (1995), In methods involving stir casting, it was found that the melt temperature varied between 780°C and 800°C. The speed of the stirring was hampered by greater dissolution or viscosity as the quantity of additional particle reinforcement increased. It was discovered via experiments that a melt temperature of 780–800°C was ideal for successfully regulating the stirring rate and producing successful dispersion of the reinforcing particles[33]. Furthermore, Lloyd (1989) conducted a study and found that the optimal temperature range for distributing particulates in aluminum alloy melts is between 740°C and 800°C. Different stirring temperatures between 350°C and 850°C have been tested by many researchers while adding reinforcements. Before adding the ingredients to the mold, mix the melt again and keep it at around the same temperature.[31].

4.1.4. Stirrer time and speed

The control of stirring speed plays a vital role in the effective development of MMCs. It is essential for maintaining refinement and preventing instability in the liquid mixture. The stirring speed is often increased to improve refinement, while too low rates might cause instability. To avoid any ripping or damage to the material, it is crucial to stir at a fair and constant pace. Therefore, it is essential to carefully regulate the stirring speed for the effective creation of MMCs. The uniform dispersion of aluminium oxide particles in AA 7075 alloy was accomplished in research by Raju et al. (2019) by increasing the stirring duration and speed (400 rpm and 10 minutes, respectively). The findings showed that the reinforcement was distributed very uniformly, which improved the created MMCs' ultimate tensile strength and microhardness[32].

4.1.5. Molding Temperature

Proper preheating of the mold is essential to prevent casting defects, such as cold shuts, which can adversely affect the properties of shaped MMCs. However, it is important to avoid excessive preheating at very high temperatures, as it can reduce the lifespan of the mold[33].

Hence, it is crucial to ensure proper preheating of the mold. A minimum mold thickness of 25 mm is required, with the thickness increasing as the size and weight of the casting increase. Various types of coatings are applied to the mold to reduce heat transfer to the mold material. These coatings help eliminate potential problems such as cracking and shrinkage defects that may arise in the molds[34)].

Below is a detailed Table 2 outlining the experimental setup and parameter variations, which addresses the reviewer's concerns regarding reproducibility and industrial applicability:

Table 2: Showing experimental setup and parameter variations for better reproducibility and industrial applicability

Bottom Pouring Stir Casting Performance Parameters	Range / Specification	Tested Values	Advantages
Type of Furnace & Temperature Controller	Digital induction furnace With ±5°C accuracy	Always maintained.	Ensures consistent and precise melt conditions throughout the experiments[26-27)].
Melting Temperature	700°C to 800°C	700°C, 720°C, 740°C, 760°C, 780°C, 800°C	Useful for the proper wettability during the casting[27-28)]. Preventing matrix alloy degradation and oxidation[28-29)].
Stirring Apparatus	High-shear mechanical stirrer. Variable speed control (calibrated to ±10 rpm).	used across all trials.	It helps in maintaining a proper dispersion of reinforcement in the matrix with minimal agglomeration[30-31)].
Stirring Speed	200 rpm to 600 rpm	200, 300, 400, 500, 600 rpm.	Lower speeds may lead to insufficient dispersion. Higher speeds can cause turbulence and gas entrainment. The chosen range achieves an optimal balance[32)].
Stirring Duration	Fixed duration	15 minutes per trial.	Ensures adequate time for complete dispersion of reinforcements before casting, promoting composite homogeneity[30-32)].

4.2. Mechanical properties of AA 6061through stir-casted

As per the given Table 3 we understand the mechanical properties of metal matrix (AA 6061) with the given reinforcement.

Table 3: Mechanical Properties of AA6061 composite

Matrix	Reinforcement			Major Outcomes			
	Type	Size (μ m)	Conc. (wt/vol Wt%)	Ultimate Strength (Max)	Hardness (Max)	Wt% of Porosity	Reference
AA 6061 (Al-Mg1SiCu)	Al_2O_3	–	2	193 (T), 361 (C)	74 HB	Low	35)
		36	20		38 BHN	-	36)
	B_4C	30	15	270 (T)	97 VHN	-	37)
		60	15	260 (T)	80 VHN	-	38)
	SiC	20	6	160 (T)	90 HV	-	39)
		35	15	265 (T)	82 HV	-	40)
		16	30	200 (T)	84 HB	Low	41)

4.3. Fabrication of Aluminium Metal Composite (MMCs) AA 6061 with different reinforcement by Stir Casting

Extensive research has led to the development of an AA 6061 composites that come in a wide variety and use both organic and inorganic reinforcements. The incorporation of the dispersed phase serves to enhance the properties of the base material by providing proper binding to the matrix. In general, the weight composition of the reinforcement in these composites varies from 5 Wt% to 30 Wt% relative to the AA 6061 alloy. Based on frequently utilized reinforcing materials, we give a thorough classification and description of AA 6061 metal matrix composites (MMCs) below.

4.3.1. AA 6061-Al_2O_3 Composites

Aluminum oxide (Al_2O_3) is a frequently utilized reinforcement material in MMCs, second only to silicon carbide. It is preferred due to its exceptional interfacial compatibility with the matrix material [42]. Aluminum oxide (Al_2O_3) is a rigid substance that represents the oxide form of aluminum. Bhaskar Chandra Kandpal successfully fabricated AA 6061/ Al_2O_3 composites using the stir-casting technique, and the obtained results were consistent with those discussed in previous sections. In the investigation, several weight fractions of Al_2O_3 (5Wt%, 10Wt%, 15Wt%, and 20Wt%) were used to reinforce AA 6061 alloy. The reinforcement particles were distributed uniformly throughout the matrix, according to Spectroscopy Electron Microscope (SEM) analysis of microstructures. As the weight percentage of Al_2O_3 rose, the composites' mechanical evaluation revealed that their ultimate tensile strength and Vickers hardness also increased as shown in Figure 5-a & Figure 5-b [43]. The results obtained from the tensile tests and hardness tests demonstrated a direct relationship between the weight fraction of Al_2O_3 and the ultimate tensile strength and hardness values.

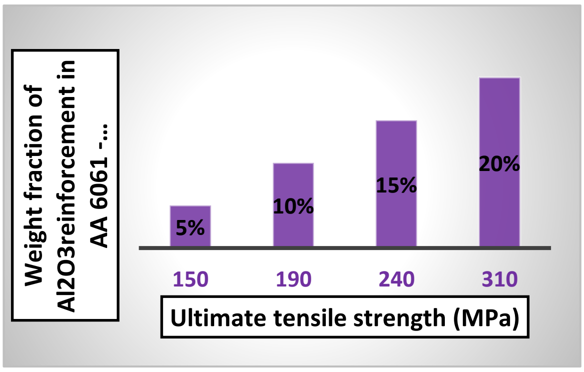

Fig.5: (a) UTS Test Values of AA6061 alloy matrix composites

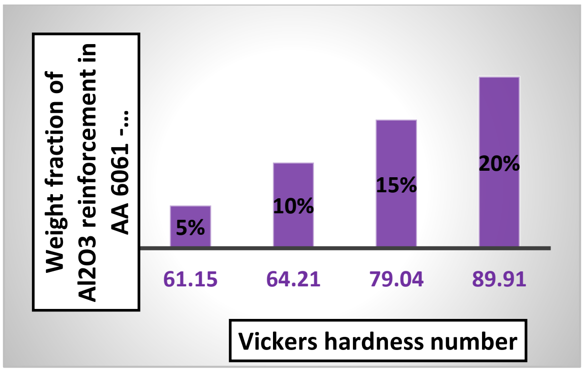

Fig.5: (b) Hardness Test values of AA6061 alloy matrix composites

4.3.2. AA 6061 SiC Composites

Silicon carbide (SiC), commonly referred to as carborundum, possesses favorable mechanical and thermal properties. Aluminium and it both have a comparable density. Due to their exceptional mechanical and tribological properties, composites made from aluminium alloy and SiC are often used in the industrial, structural, and aviation sectors. One of the most resilient materials, Silicon Carbide (SiC), is only slightly harder than diamond. Carborundum is another name for it. SiC exhibits exceptional mechanical and tribological characteristics which make it a popular choice in the defense and space sectors[44]. In a study by S. Sivananthan et al[45], they used a stir casting method to reinforce AA 6061 alloy with SiC particulates, ranging from 0Wt% to 4Wt% in weight. The aim was to examine how the addition of reinforcement affected the mechanical properties of the composite. The results indicated that the composite materials outperformed the base alloy across various properties. In particular, the hardness, tensile strength, and compression strength of the composite increased by 25Wt%, 25.6Wt%, and 12Wt%, respectively, in comparison to the AA 6061 alloy alone when it included 4Wt% SiC. The electromagnetic stir casting process is used to fabricate an AA 6061/SiC composite with various weight fractions (0Wt%, 1Wt%, 2Wt%, 3Wt%, and 5Wt%)[46]. The scanning electron microscopy analysis confirmed the absence of particle clumping and the uniform distribution of SiC particles. The density, hardness, and tensile strength of the alloy were all significantly improved over the basic alloy as a consequence of the addition of these particles. Consequently, the stirring action facilitated the uniform dispersion of the reinforcement particles throughout the material, thereby leading to the subsequent improvement in its mechanical properties[47-49].

4.3.3. AA 6061 TiC Composites

The incorporation of Titanium Carbide (TiC) particles in composites has shown outstanding bonding properties, particularly with aluminum. These composites have gained recognition as efficient and promising reinforcements, resulting in enhanced material properties including wear resistance, microhardness, and compressive strength. Additionally, TiC particles have been recognized as reliable reinforcements that provide improved corrosion resistance in metal matrix composites (MMCs). [50]. S. Gopalakrishnan et al. utilized an enhanced stir casting method to fabricate an AA 6061-TiC particulate-reinforced composite. The addition of magnesium improved wettability, while argon gas prevented reactions with the molten matrix material. Because TiC resists plastic deformation, the final composites with no defects showed enhanced specific strength with increasing TiC concentrations. Furthermore, as was discovered via wear research utilizing a pin-on-disc machine[51], the composite material's wear resistance was enhanced. An AA 6061-TiC metal matrix composite (MMC) was also successfully created by M.S. Raviraj et al. utilizing the stir casting technique. The inclusion of TiC effectively refined the grain structure, contributing to enhanced strength in the composites[52].

4.3.4. AA 6061 B_4C Composites

Boron carbide (B_4C) is a solid material with a black appearance and metallic luster. One of the toughest ceramic substances known to exist on Earth, it is well-known[53]. The exceptional thermal and chemical stability of boron carbide (B_4C) makes it an attractive material for reinforcement purposes. In comparison to Al_2O_3 and SiC, it has a greater hardness (HV) of 30 GPa and a lower density of 2.52 g/cm3, which adds to its attraction. B_4C finds applications in the manufacturing of military tanks and bulletproof jackets. Consequently, the fabrication of B_4C-reinforced MMCs using the economical stir casting method has garnered significant attention and interest[54]. B. Ravi et al. successfully fabricated composites containing 5Wt% and 10Wt% of B_4C particles. The investigation showed that the particles were evenly scattered within the AA 6061 matrix, thanks to effective stirring and appropriate process variables. The strong reinforcing particles on the surface of the composite, which prevented plastic deformation, increased its hardness. Additionally, the strengthened interfacial bonding between the reinforcement and matrix allowed for efficient load distribution and transmission from the matrix to the reinforcement. As a consequence, the composite's ultimate tensile strength (UTS) rose[55]. In their study, Bhujanga D. P. et al. investigated the wear characteristics of composites made from AA 6061 alloy reinforced with B_4C particles. They discovered that the wear resistance of the composite material improved as the weight fraction of B_4C increased. The addition of these hard ceramic particles to the ductile AA 6061 matrix led to a significant enhancement in wear performance[56]. B. Manjunatha et al. showed that the AA 6061-B_4C composite, produced using stir casting, could undergo extrusion to improve particle distribution, reduce particle size, and eliminate casting defects. Furthermore, they found that applying heat treatment could enhance the mechanical properties of the composite[57]. The stir casting technique has proven to be successful in fabricating AA 6061-B_4C composites with a high B_4C content of up to 31Wt% by weight. Through the use of vacuum stirring and progressive reinforcement addition, the B_4C particles were uniformly distributed within the composite. The resulting AA 6061-31Wt% B_4C composite displayed a high ultimate tensile strength of 340 MPa. These highlights stir casting as a highly promising method for producing AA 6061-B4C composites[58]. With different weight percentages of B4C reinforcement (4, 6, 8, 10, and 12 Wt%), K. Kalaiselvan et al. effectively created AA 6061-B4C composites via stir casting. They saw that the B_4C granules were distributed uniformly throughout the composite. To improve the wettability of B_4C particles with the aluminum melt, they added K_2TiF_6 flux. The flux reacted with the molten surface, generating localized heat near the interface. Higher weight percentages of B_4C particles improved the composites' tensile strength and hardness[59].

4.3.5. AA 6061 Matrix hybrid Composites

These composites are composed of two or more reinforcements, which may be biological or inorganic in makeup. It has been shown that applying secondary reinforcements in addition to main reinforcement results in superior characteristics. The hybrid composites have enhanced thermal and mechanical characteristics. The properties of the produced composites may be improved by varying the hybrid reinforcements' composition and concentration. Higher concentrations of hybrid Metal Matrix Composites (MMC) are associated with increased agglomeration and porosity, which can have a detrimental effect on the fatigue, creep, and impact strength of the material[60]. Aluminum-based hybrid materials, customized to specific requirements, demonstrated exceptional mechanical properties and coefficients of thermal expansion. The widely adopted method for developing such materials is stir casting. By scientifically optimizing the quantity and types of constituent materials in hybrid composites, the characteristics of the materials can be modified[61]. The technique of stir casting is utilized for the development of hybrid nano-composites of aluminum as well. By incorporating appropriate reinforcements in optimal quantities, the mechanical, micro-structural, and tribological properties of the composites are enhanced[62]. Table 4 summarizes the research investigations done on the hybrid AA 6061 composites stir-casting technique.

Table 4: Summarizes the research investigations done on the hybrid AA 6061 composites stir-casting technique

Authors	Composition and Reinforcements	Remarks (Synthesis and Characterization)	Reference
C. Elanchezhian et al.	Graphite, silicon, zinc, and chromium (each in amounts of 0.5, 1, and 1.5Wt%)	Increase in AA 6061 matrix's hardness, yield strength, and tensile strength by adding particles like alumina, silicon, zinc, chromium, and others. But it was also followed by a decline in ductility. On the other hand, adding graphite to the aluminium matrix increased the material's tensile strength and elastic modulus at the expense of hardness.	[63]
Dhanashekar et al.	0 Wt%, 2.5Wt%, 5 Wt% and 7.5 Wt% SiC	The mechanical characteristics, such as hardness and compressive strength, were assessed, and a metallographic analysis was conducted.	[64]
Ezatpour et al.	0.5Wt%, 1Wt% Wt% and 1.5 Wt% nano-Al_2O_3	The microstructural composition and mechanical attributes, including ductility and tensile strength, were investigated.	[65]
Gireesh et al.	(a) 5Wt% SiC 5 Wt% Al_2O_3 5Wt% Fly ash, (b) 7.5 Wt% SiC 7.5 Wt% Al_2O_3 5 Wt% Fly ash and (c) 10 Wt% SiC 10Wt% Al_2O_3 5 Wt% Fly ash	The mechanical characteristics of the synthesized hybrid MMCs, such as hardness, strength, and wear resistance, were assessed and analyzed.	[66]
Gopalakrishnan and Murugan	3 Wt%, 4 Wt%, 5 Wt%, 6 Wt% and 7 Wt% TiC	The investigation focused on assessing and analyzing the wear resistance, ductility, strength, and microstructure of the materials.	[51]
Kalaiselvan et al.	4 Wt%, 6 Wt%, 8 Wt%, 10 Wt% and 12 Wt% B_4C	The metallographic properties, tensile strength, and microhardness, of the material were examined and evaluated.	[59]
Kandpal et al.	5 Wt%, 10 Wt%, 15 Wt% and 20 Wt% Al_2O_3	The microstructure, microhardness, and tensile strength of the material were investigated and analyzed.	[43]
Karakoça et al.	5 Wt%, 10 Wt%, 15 Wt% and 20 Wt% B_4C	The hardness and strength of the material were measured, and a metallographic examination was performed.	[67]
Kumar and Kumaraswamidhas et al.	0 Wt%, 3 Wt%, 6 Wt%, 9 Wt% and 12 Wt% (AlN and ZrB[2]).	The synthesized hybrid MMC underwent analysis using XRD, along with a characterization of its microstructure, and an investigation into its wear characteristics.	[68]
Kumar et al.	0 Wt%, 2 Wt%, 4 Wt% and 6 Wt% SiC	The hardness, wear resistance, and ultimate tensile strength (UTS) of the synthesized MMC were all assessed.	[69]
Kumar et al.	2 Wt%, 4 Wt%, 6 Wt% and 8 Wt% Al_2O_3		[70]
LI et al.	31 Wt% B_4C	It was examined metallographically and tested for tensile strength and X-ray diffractograms.	[71]
Marachakkanavar et al. Phanibhushana et al. Rao and Ramanaiah	0 Wt%,2 Wt%,4 Wt% and 6Wt% Fe_2O_3 0 Wt%, 2 Wt%, 4 Wt%, 6 Wt% and 8 Wt% Fe_2O_3 1 Wt%, 2 Wt%, 3 Wt%, 4Wt% and 5 Wt% MoS_2	The study was concerned with determining the material's hardness and tensile strength. The effects of heat treatment on corrosion resistance and mechanical qualities were specifically examined during a thorough examination of wear strength.	[72] [73] [74]

Moses et al.	15 Wt% TiC	The impact of various process parameters in stir casting on the strength and toughness of the material was studied. Additionally, a detailed microstructural analysis was conducted.	75)
Moses et al.	0 Wt%, 5 Wt%, 10 Wt% and 15 Wt% SiC	The mechanical properties, including hardness and tensile strength, were evaluated, and a thorough metallographic examination was conducted.	49)
Panwar et al.	4 Wt%, 8 Wt%, 12 Wt%, 16 Wt% and 20 Wt% red mud	The synthesis of the composite material was conducted, and a detailed microstructural analysis was performed using red mud as the reinforcement.	76)
Pitchayyapillai et al.	1Wt% and 2 Wt% nano Silver	Analysis was done on the effects of adding silver nanoparticles as reinforcement on strength (both compressive and tensile), wear resistance, and microstructure.	77)
Pitchayyapillai et al.	(a) 4 Wt% Al_2O_3 2 Wt% MoS_2 (b) 4 Wt% Al_2O_3 4 Wt% MoS_2 (c) 4 Wt% Al_2O_3 6 Wt% MoS_2 (d) 8 Wt% Al_2O_3 2 Wt% MoS_2 (e) 8 Wt% $Al_2O_3$4 Wt% MoS_2 (f) 8 Wt% $Al_2O_3$6 Wt% MoS_2 (g) 12 Wt% $Al_2O_3$2 Wt% MoS_2 (h) 12 Wt% Al_2O_3 4 Wt% MoS2 and (i) 4 Wt% Al_2O_3 6 Wt% MoS_2	The investigation focused on studying the wear strength and conducting microstructural analysis.	78)
Prabhu et al.	1 Wt%, 2 Wt%, 3 Wt% and 4 Wt% rutile	A comprehensive evaluation was conducted to analyze the microstructure of the material and assess its mechanical properties, including hardness and strength.	79)
Rahman and Jayahari	5 Wt% and 10 Wt% steel chips	Tensile strength and wear strength, in particular, were evaluated as part of the material's mechanical properties.	80)
Ravi et al. Manjunatha, et al.	0 Wt%, 5Wt%, and 10 Wt% B_4C 1.5–10Wt% B_4C	The research investigated the material's toughness, strength, and microstructure. Examining the impact of mechanical and thermal loads on the installation of reinforcements.	55) 57)
Raviraj et al.	3 Wt%, 5 Wt% and 7 Wt% TiC	The study focused on investigating the tensile strength and microstructure of the material.	52)
Sachinkumar et al., 2020	SiC (10 Wt%) Fly ash (0, 2.5, 5, 7.5, and 10 Wt%)	The ultimate tensile strength (UTS) and microhardness were increased by adding fly ash up to 7.5Wt% by weight.	81)

Sharma et al.	(a) 2.5 Wt% Al_2O_3 2.5 Wt% SiC, (b) 2.5 Wt% Al_2O_3 2.5 Wt% SiC0.5 Wt% CeO_2 (c) 5 Wt% Al_2O_3 5 Wt% SiC, (d) 5 Wt% Al_2O_3 5 Wt% SiC 1.5 Wt% CeO_2 (e) 7. 5 Wt% Al_2O_3 7.5 Wt% SiC (f) 7. 5 Wt% Al_2O_3 7.5 Wt% SiC with 2.5 Wt% CeO_2		82)
Sharma et al.	(a) 5 Wt% (Al_2O_3 and SiC), (b)10 Wt% (Al_2O_3 + SiC), (c) 15Wt% (Al_2O_3 + SiC), (d) 5 Wt% (Al_2O_3 + SiC) + 0.5 Wt% CeO_2 (e)10 Wt% (Al_2O_3 + SiC) + 1.5 wtWt% CeO_2 (f) 15Wt% (Al_2O_3 + SiC) + 2.5 Wt% CeO_2	The investigation was focused on determining how the wear strength of the synthesized hybrid metal matrix composite (MMC) would change with the addition of rare earth elements.	83)
Sivananthan et al.	0 Wt%, 2Wt% and 4Wt% SiC	The evaluation involved assessing the hardness, tensile strength, and compression strength of the material.	45)
Sozhamannana, et al.	3Wt% nano TiC and 10 Wt% nano Gr	The hybrid reinforced metal matrix composite (MMC) was subjected to analysis to investigate its microstructure and wear strength.	84)
Wang et al.	20 Wt% SiC	The study focused on examining the influence of particulate distribution on the mechanical properties of the material.	44)
Yashpal et al.	Alumina (5Wt%) and bagasse ash (8Wt%)	Hybrid composites with smaller particle size reinforcements exhibited improved mechanical properties compared to the base alloy.	85)

4.3.6. AA 6061 Composites with Other Reinforcement

By employing stir casting, researchers have successfully manufactured Aluminum Alloy 6061 composites with different reinforcements other than SiC, B_4C, Al_2O_3, and TiC. Aluminium Matrix Composite (AMC) was created by stirring the AA 6061 matrix with iron added throughout the process[72]. In the study, the researchers found that AA 6061 alloy had an ultimate tensile strength of 173.3 N/mm^2. However, they observed a significant improvement in strength when they introduced 6 Wt% iron ore as reinforcement in the composite. The strength of the AA 6061/6 Wt% iron ore composite increased to 240.5 N/mm^2, representing a substantial 38 Wt% enhancement. The hardness of the material also saw a remarkable increase, rising from 72 to 103 BHN when the iron ore content was increased from 0 to 6 Wt%, resulting in a significant 45Wt% improvement. Scanning electron microscopy (SEM) images confirmed the uniform distribution of iron ore particles within the AA 6061 matrix, indicating a strong and well-established bond between the matrix and the reinforcement.

In the research study, the composite material was reinforced with varying weight fractions of iron ore, specifically 2Wt%, 4Wt%, and 6Wt%. To optimize the properties of the cast samples, a three-stage heat treatment process was implemented. This process involved solution treatment, followed by quenching and aging steps. Researchers have effectively integrated rutile, a naturally occurring type of TiO_2, into the matrix of the AA 6061 alloy by the stir-casting process. In addition to having better mechanical, tribological, and electrical characteristics, rutile also had a reduced thermal expansion coefficient[79]. SEM examination verified the matrix's uniform distribution of rutile particles. Because the composites had tougher and denser rutile particles, they demonstrated greater density and hardness than the AA 6061 alloy.

In comparison to the unreinforced alloy, the hardness values of the composites improved by 15Wt%, 24Wt%, 36Wt%, and 44Wt%, respectively, upon adding reinforcement at weight fractions of 1Wt%, 2Wt%, 3Wt%, and 4Wt%. The tensile strength also experienced enhancements of 5Wt%, 10Wt%, 14Wt%, and 7Wt%

respectively. However, it was observed that exceeding a 3Wt% of reinforcement did not have a beneficial impact on the tensile strength. This was attributed to the tendency of rutile particles to agglomerate and the non-uniform distribution within the composite.

Md Sumair et al. used steel machining chips as reinforcement in the AA 6061 matrix in their investigation. These chips were in the shape of a powder, and their 40–60 micron-sized particles. 5Wt% and 10Wt% weight fractions of these chips were added to the composite using the stir-casting technique. The inclusion of steel chips led to improvements in both the tensile strength and hardness of the composites compared to the properties of the unreinforced matrix material. Additionally, as the weight fraction of steel chips increased, the wear index decreased. This can be attributed to the fact that steel chips are harder than aluminum, imparting higher resistance when subjected to wear[80]. Using the stir-casting method, researchers successfully developed an Aluminum Matrix Composite (AMC) by incorporating glass particulates into the AA6061 alloy[52]. The composites were fabricated with varying volume fractions of glass, including 3Wt%, 6Wt%, 9Wt%, and 12Wt%.

The study found that the hardness and tensile strength of the composites increased as the volume fraction of glass reinforcement rose, up to a 9Wt% volume fraction. However, for the composite with a 12Wt% glass content, the presence of agglomeration and pores led to a decrease in both hardness and tensile strength. Notably, the tensile strength exhibited significant improvement, increasing from 119 MPa to 192 MPa. This improvement may be ascribed to the reinforcement's greater ability to cause dislocations. These extra dislocations reduced the mobility of dislocations, which in turn increased the composite's tensile strength[86]. The researchers utilized the stir-casting method to create composites of AA 6061 alloy with hematite (Fe_2O_3), an iron oxide abundant in nature. Hematite is harder than pure iron but also more brittle. Hematite particles were used to create the composites, with weight fractions ranging from 0 to 8 Wt% and increments of 2 Wt% [73]. Chethan K. N. et al. looked into the viability of using bamboo charcoal particles as a reinforcement in the AA 6061 matrix and evaluated its effect on the mechanical characteristics in their study. In the investigation, bamboo charcoal weight fractions of 2Wt%, 4Wt%, and 6Wt% were included in the matrix. The composites' hardness value increased as a consequence of the carbon present in the bamboo charcoal reinforcement. Among the samples, the composite with a 6Wt% weight fraction of bamboo charcoal, which was cooled in a furnace, exhibited the highest hardness, measuring 112 VHN. The AA 6061 alloy's hardness, which was evaluated at 105 VHN, was much lower than this number. However, it was observed that the tensile strength of the composites decreased as the bamboo charcoal content increased in all the composite samples[87]. Due to the high cost of the material and challenges related to wetting the reinforcement, limited studies have been conducted on Aluminum Matrix Composites (MMCs) reinforced with molybdenum disulfide (MoS_2). MoS_2 is a strong and chemically stable material with a low density of 2.52 g/cm3. In this research, stir casting was utilized to fabricate composites of AA 6061 alloy with varying weight fractions (1Wt%, 2Wt%, 3Wt%, 4Wt%, and 5Wt%) of MoS_2. The hardness measurements showed that the composite with 1Wt% MoS_2 had a hardness value of 65 HV. As the MoS_2 content was gradually increased to 4Wt%, a significant increase in hardness was observed, reaching 109 HV. Heat treatment of the composites further improved their hardness compared to the as-cast samples. The composite with 4Wt% MoS_2 addition exhibited the highest hardness. Similar trends were observed in yield strength and ultimate tensile strength (UTS) measurements. However, when the MoS_2 content exceeded 4Wt% by weight, the mechanical properties of the composites started to decline. This decrease may be attributed to the presence of porosity or defects introduced during the stir-casting process[74]. Researchers successfully used industrial waste to produce a better material with affordable reinforcing, supporting sustainability. By adding different organic and inorganic elements as reinforcements during the stir-casting process, it can be inferred that the characteristics of the AA 6061 alloy may be improved.

4.3.7. Nanocomposites based on the AA 6061 matrix

The utilization of nano-sized particle-reinforced metal matrix nanocomposites (MMNCs) offers significant advantages in terms of enhanced ductility, strength, and improved wear resistance compared to conventional metal matrix composites (MMCs) reinforced with larger-sized particles. These superior material properties make MMNCs a preferable choice for various industrial applications, due to their potential to deliver superior performance and durability in demanding conditions[88]. The mechanical, tribological, physical, and interfacial properties of the base material are noticeably improved when nanoscale reinforcement particles are added to an aluminium alloy matrix, according to research. The manufacture of AA 6061-nano Al_2O_3 composites with different reinforcement weight percentages (1.0, 1.5, 2.0, 2.5, and 3.0 was accomplished with success utilizing ultrasonic-assisted stir casting. Through this process, a notable reduction in porosity was observed, indicating improved material quality compared to traditional stir-casting fabrication methods[89]. The ultrasonic-assisted stir-casting method employs an ultrasonic vibrating probe to achieve the uniform dispersion of nanosized particles within the molten pool. The probe is positioned at a specific depth in the molten charge and activated to generate vigorous vibrations. This creates high-energy waves that induce the formation of cavitation bubbles. These bubbles experience extreme pressure and temperature, leading to their spontaneous collapse and the release of energy. This phenomenon helps break up clusters and agglomerations of nano-particles, promoting their uniform distribution in the molten material. The molten composite that results is then transported to a mold that has already been heated up to minimize stress concentration and to enable controlled cooling, providing the appropriate material properties[90]. Through the use of stir casting, AA 6061 nano-composites with nano-silver (Ag) reinforcement were created. The nano-composites outperformed ordinary aluminium alloys in terms of mechanical characteristics and wear resistance, comprising 1 and 2 weight percent of nano-silver respectively[77]. The tribological behavior of hybrid composites made by stir casting of AA 6061, nano TiC and graphite was investigated in a work by Sozhamannan G. et al. The composites were made up of a matrix that included graphite (10 Wt%) and TiC reinforcing particles that were dispersed equally (3 wt Wt%). When compared to the base alloy, the wear rate was 4.7Wt% lower due to the presence of these reinforcements in the matrix, which prevented plastic deformation during the wear process. The hybrid composite also showed a notable decrease in weight loss during the wear test, displaying a 23.33Wt% reduced weight loss in comparison to the unreinforced AA 6061 matrix[84]. Ezatpour et al.successfully produced AA 6061/nano Al_2O_3 composites using the stir-casting method. Higher yield strength, ultimate strength, and hardness in comparison to the alloy matrix were some of the enhanced attributes brought on by the inclusion of nano-sized Al_2O_3 particles in both the as-cast and extruded states[65].

5. Discussion

The analysis of the composites' mechanical properties demonstrated that as the proportion of reinforcement increased, there was an enhancement in tensile strength, compressive strength, and hardness. The composites' wear properties were significantly improved by the inclusion of reinforcing particles. The addition of reinforcement caused the grain size to be reduced. It is crucial to keep in mind, nevertheless, that going above a specific weight fraction threshold could negatively affect the attributes. This is due to the possibility of increased porosity, agglomeration, and uneven particle distribution, which would reduce the overall performance of the composites. A variety of reinforcements are often used to create AA 6061 Aluminium Matrix Composites (MMCs). The ability to enhance the characteristics of composite materials makes SiC, Al_2O_3, B_4C, and TiC popular options. In addition, materials including glass, iron ore, red mud, hematite, steel machining chips, and bamboo charcoal have been employed as reinforcements. Stir casting has proved effective in establishing an even distribution of reinforcements throughout the matrix, leading to good matrix-reinforcement bonding. Incorporating two or more different kinds of reinforcing particles, hybrid AA 6061 composites have shown better characteristics. Based on the precise required qualities, reinforcements may be chosen. The body of existing research suggests that secondary reinforcements improve the characteristics of composite materials. The ideal amount of each reinforcement and process parameter may be determined via scientific optimization. Every sort of reinforcement used in hybrid composites, which are reinforced from different materials, may help the composite's mechanical qualities in some way. There is, however, a chance that it could have a detrimental effect on other qualities. Hybrid AA 6061 composites may be successfully modified according to desired qualities and applications. The best technique for creating these composites without any porosity is stir casting. Utilizing agricultural and industrial waste items as dispersed phases, such as rice husk, bamboo charcoal, and fly ash, is a developing trend. However, it is essential to keep the number of reinforcements to the ideal weight fraction to avoid material flaws. A noticeable pattern could be seen in the AA 6061-alumina-molybdenum disulfide hybrid composite's mechanical characteristics and wear resistance. The mechanical characteristics and wear resistance were enhanced by adding more alumina. A larger weight percentage of MoS_2 particles did, however, cause a decrease in the composite's tensile strength and hardness. However, the inclusion of MoS_2 improved the wear and friction resistance of the composite. To improve the overall mechanical, microstructural, and tribological characteristics of composites, suitable reinforcements must be carefully chosen and combined in the right amounts. Further investigation is needed in several study areas related to the stir casting method's use in the manufacture of AA 6061 Metal Matrix Composites (MMCs). First, by maximizing variables like the stirring process, squeezing pressure, and ultrasonication duration, it is possible to minimize porosity in the created composites. The mechanical characteristics of AA 6061 MMCs should also be examined concerning the influence of innovative nanoscale reinforcing materials. Another crucial factor may be addressed by using techniques like ultrasonic-assisted stir casting and alterations to the container and stir blade designs to achieve a homogenous distribution of reinforcement particles inside the matrix. Another interesting topic for research is how to use additives and appropriate reinforcement materials to improve the interfacial bonding between the reinforcement material and the AA 6061 base alloy. The development of this sector may also be aided by investigating sustainability issues, including recycling techniques for producing AA 6061 MMCs, as well as by using innovative methodologies

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and modeling procedures [91–92].

Metal Matrix Nanocomposites (MMNCs) made from AA 6061 have improved mechanical characteristics as a result of stir casting. Only 14Wt% of the literature review's articles focused on AA 6061 nanocomposites, indicating that there hasn't been much in-depth study on this particular subject. The development of porosity is one of the main difficulties faced throughout the procedure. Using reinforcement particles that are nanoscale in size might result in unequal dispersion within the matrix since they have a greater surface-to-volume ratio and poor wettability. The composite characteristics are adversely impacted by the non-uniform particle dispersion. In addition, composite properties deteriorate when the appropriate weight % of reinforcement is exceeded. Higher reinforcement content levels may aggregate and cluster nanoparticles, further degrading the material's properties. The volume of the porosity is also influenced by an increase in the nanoparticulate concentration. Therefore, careful management of the supply of reinforcement is essential to properly address these problems.

According to the existing research, it has been proposed that combining the squeeze casting and ultrasonic-assisted stir casting procedures may significantly decrease porosity and guarantee a more uniform distribution of nanoparticles[93]. To achieve homogeneous dispersion of nanoparticles inside the matrix, ultrasonic vibration is extremely helpful. An ultrasonic vibrator's powerful vibration helps keep the particles in composites from aggregating and agglomerating. An ultrasonic probe's powerful ultrasonic vibrations cause acoustic streaming and potent cavitation effects. In the vicinity of clusters of reinforcement particles, transient cavitation events help break down gas microbubbles, distributing them uniformly in the molten pool. Additionally, the stirring process is enhanced and greatly improved in terms of efficacy by acoustic flow, which is the movement of liquid brought about by acoustic pressure gradients[94]. Researching the stir casting method for AA 6061 composites requires careful consideration of microstructural analysis. To evaluate the effectiveness of the manufacturing procedure, it entails looking at the distribution of reinforcements inside the matrix phase. A homogeneous distribution of reinforcements is sought to produce improved characteristics in Aluminium Matrix Composites (MMCs). The microstructural study ought to show an intra-granular distribution of reinforcements with a distinct matrix phase interface. The efficacy of the stir-casting process and its influence on the final qualities of the composites under study must be understood in light of this discovery. Finding unfavorable elements including holes, voids, clusters, and agglomerations that may have a negative impact on the material characteristics requires a close investigation of the microstructure. Researchers can evaluate the quality of the composite material and spot any structural irregularities that can impair its performance by examining the microstructure. In order to maintain the integrity and usefulness of the material, it is essential to identify and characterize these unwanted traits.

6. Application of Aluminium Alloy AA 6061

Aluminum Metal Matrix Composites (AlMMCs) have emerged as highly promising materials for a wide range of industrial applications, especially in the automotive sector. Their exceptional combination of high strength, cost-effectiveness, and lightweight characteristics makes them attractive for use in aviation, mechanical engineering, electrical systems, automotive manufacturing, electronics, and transportation industries.

AA-6061 composites have emerged as a promising material for aerospace applications due to their enhanced strength-to-weight ratio and fatigue resistance, which are critical for components such as aircraft fuselages, wings, internal panels, door panels, chassis parts, and both internal and external trunk panels. Recent studies, such as those by Awate et al.[95] and Kotteda et al.[96], have demonstrated that incorporating graphene reinforcements can significantly improve the mechanical properties of AA-6061 alloys. Awate et al.[95] reported that optimized processing conditions not only enhance microstructural homogeneity but also lead to a notable increase in yield strength, making these composites a competitive alternative to conventional aerospace materials. Additionally, Kotteda et al.[96] provided experimental evidence showing that with the use of high specific strength materials for such fuselage structure greatly reduces the emissions generated by air vehicles, thereby supporting the potential of these composites to withstand the rigorous operational demands of aerospace environments.

In the defense sector, AA-6061 composites are being explored for their superior impact resistance and energy absorption capabilities, which are essential for ballistic protection and armored vehicle applications. Research by Karabulut et al.[97] has shown that reinforcing functionally graded (FGM) Al6061 composites reinforced with boron carbide (B_4C), silicon carbide (SiC), and alumina (Al_2O_3) not only enhances microhardness, impact resistance and tensile strength but also contributes to significant weight reduction- a critical factor in ballistic protection in defense design. The highest ballistic protection was achieved with B_4C-reinforced laminated FGM at an impact speed of 664.25 m/s with a penetration depth of 14 mm, while the impact speeds of SiC- and Al_2O_3-reinforced FGMs were 500.88 and 435.23 m/s, respectively. These studies collectively suggest that AA-6061 composites hold great promise for developing lighter yet robust protective systems that meet the stringent requirements of modern defense applications. Figure 6 shows the diverse application areas of AlMMCs. Aluminium Metal Matrix

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Composites (AlMMCs) are gaining widespread application across diverse sectors due to their exceptional mechanical properties such as high strength-to-weight ratio, wear resistance, thermal stability, and corrosion resistance. In the rail and marine sectors, they are used in train body structures and shipbuilding components[98-100]. The electronics industry employs AlMMCs in antennas and capacitors[103-106], while the construction sector benefits from their use in roofs and wall panels[107-112]. Defence applications include missiles, battle tanks, rockets, and submarines[113-117]. In the automotive sector, AlMMCs are utilized in car frames, wheels, electric wiring, and AC systems[117-120]. Aerospace uses include fuselage and wiring components[121-125].

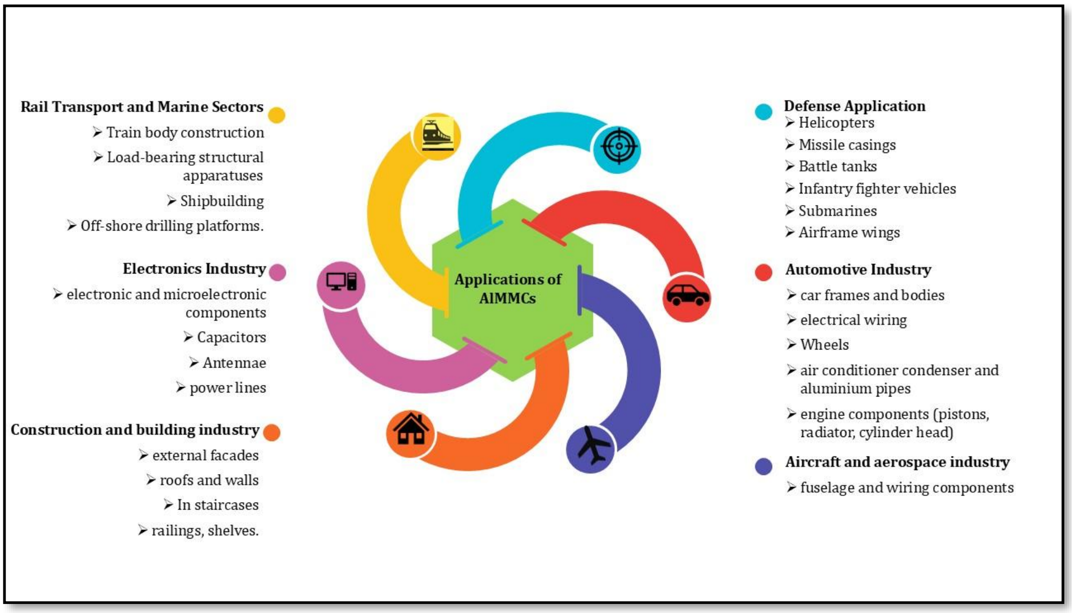

Fig. 6: Application of Aluminium Alloy AA 6061

7. Future Scope of Aluminium Alloy AA 6061

The prospects of Aluminum Alloy AA 6061 are promising, with several potential advancements and applications on the horizon. Here are some areas that hold promise for the future development of AA 6061:

Lightweight Structures: AA 6061's excellent strength-to-weight ratio makes it ideal for lightweight structural applications. In the future, we can expect to see increased usage of AA 6061 in industries such as automotive, aerospace, and construction, where weight reduction is crucial for improved fuel efficiency and performance.

Advanced Manufacturing Techniques: The development of advanced manufacturing techniques, such as additive manufacturing (3D printing), opens up new possibilities for complex and customized designs using AA 6061. This technology allows for the efficient production of intricate components with reduced material waste.

Enhanced Mechanical Properties: Ongoing research focuses on further enhancing the mechanical properties of AA 6061, such as tensile strength, hardness, and fatigue resistance. This involves exploring new alloying elements, heat treatments, and processing techniques to optimize the material's performance in demanding applications.

Corrosion Resistance: Improving the corrosion resistance of AA 6061 is another area of interest. Researchers are investigating surface treatments, coatings, and alloy modifications to enhance the alloy's resistance to various corrosive environments, expanding its potential use in marine, chemical, and other corrosive environments.

Sustainable Manufacturing: With an increasing focus on sustainability, there is a growing demand for environmentally friendly manufacturing processes. Future developments in the production of AA 6061 alloys may prioritize energy efficiency, reduced emissions, and the use of recycled materials, aligning with the principles of the circular economy.

Integration of Nanotechnology: Nanotechnology holds promise for enhancing the properties of AA 6061. The incorporation of nanoscale reinforcements, such as nanoparticles or nanofibers, can significantly improve strength, toughness, and thermal stability. This opens up new opportunities for advanced applications in various industries.

Multifunctional Applications: Exploring the multifunctional capabilities of AA 6061 is an emerging research area. By incorporating additional functionalities, such as electrical conductivity, thermal management, or self-healing properties, AA 6061 can be tailored for diverse applications ranging from electronic devices to smart structures.

These are just a few potential future directions for Aluminum Alloy AA 6061. Continued research and development efforts are likely to unlock even more opportunities, expanding the alloy's range of applications and further improving its performance characteristics.

8. Conclusion

The following findings may be reached after reviewing the material that is currently accessible.

By maximizing stir-casting process variables such as stirrer speed, stirring duration, stirrer blade design, reinforcement size, and melt temperature, the characteristics of AA 6061 composites may be efficiently controlled. The required properties of the AA 6061 composites may be attained by fine-tuning these parameters.

The weight proportion of reinforcing particles affects the AA 6061 composites' characteristics. The characteristics are improved by increasing the weight fraction, however going above a certain point causes pore development and agglomeration. Researchers have looked at creating sustainable composites utilizing industrial waste, such as fly ash.

Hybrid AA 6061 composites with improved characteristics were created using stir casting.

Only a small amount of study has been done on stir-cast nanocomposites and porosity and uneven distribution have been noted as problems.

Future research should concentrate on producing metal matrix nanocomposites efficiently employing methods like squeeze casting and ultrasonic-assisted stir casting to enhance characteristics.

AA 6061 composites have been made using the stir-casting technique and reinforced with a variety of organic and inorganic elements. Compared to the basic alloy, these composites have shown to have better characteristics,making AA 6061 a highly sought-after option for a variety of applications.

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