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Self-Healing Aluminium Matrix Composite Materials for Aerospace Industry – A Review

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ABSTRACT
This review paper looks at the concept of self-healing, its advantages, processes and challenges as it affects its application in Aluminium metal matrix composites (AMCs).it was established, that though, there are two popular methods of producing self-healing AMCs, many efforts have been concentrated on the stir casting method by researchers despite the inherent advantages of mechanical strength possessed by composites through powder metallurgy method. Therefore, research is still needed to fully understand the impact of introducing self-healing agents through the powder metallurgy method on the pre-and post-healing mechanical properties of AMCs. This will help achieve the best mechanical properties of AMCs for application in aerospace industries.
Keywords: Self-healing, powder metallurgy, stir casting, Aluminium Metal composites.

I. INTRODUCTION

Composite materials have found extensive applications in the aerospace industry, being utilized in various structural components such as rocket motor castings, antenna dishes, engine nacelles, stabilizers, wing boxes, wings, bulkheads, landing gear doors, engine cowls, floor beams, cones, flap track panels, and more.[1] Self-healing polymer materials possess the remarkable ability to repair themselves when a crack forms in the material. Repairing damage is crucial for self-healing materials. Self-healing polymer-based composites have the ability to repair damage through either extrinsic or intrinsic methods. The extrinsic technique involves encapsulating the healing agent in reservoirs such as microcapsules, hollow fibers, and microvascular networks. When microcapsules or hollow fibres rupture or dissolve, healing agents with low viscosity are released in the damaged area, effectively filling the affected region. Alternatively, the intrinsic healing method relies on the chemical, physical, and supramolecular interaction of polymers, as depicted in Figure 1. Numerous researchers have delved into the realm of self-healing composites, exploring the obstacles they present and the benefits they offer in the field of aerospace engineering. In their research paper titled "Manufacturing Challenges in Self-Healing Technology for Polymer Composites - A Review," JE, Sultan [2]and their team explored the intricacies of creating self-healing materials for polymer composites. They found that there are various methods to create these materials using different parameters and substances. However, the manufacturing process presents its own set of difficulties, including preparing the carrier for the healing agent, embedding the reinforcement, and ensuring the best healing performance.

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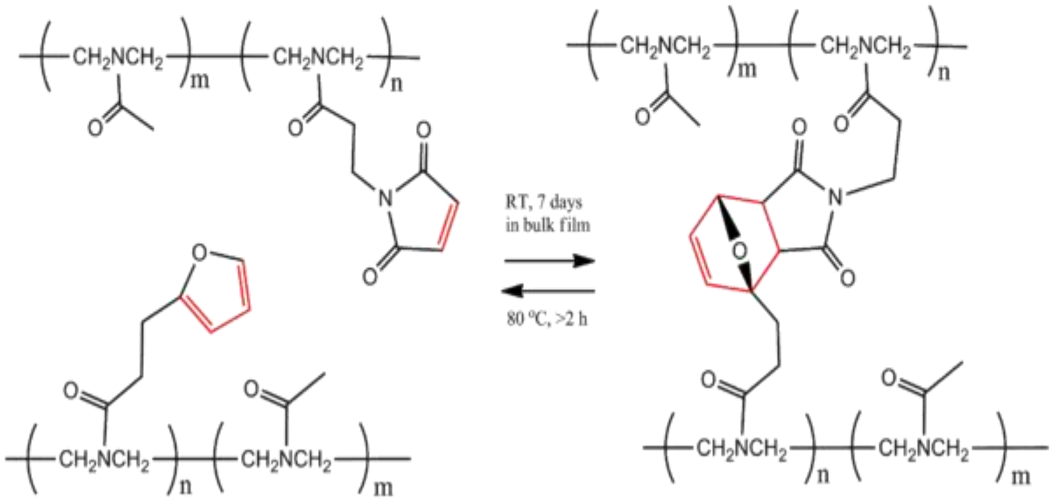

Figure 1: Figure 1 illustrates the process of reversible polymer cross-linking through the Diels-Alder cycloaddition reaction between furan and maleimide.[4]

The researchers examined different self-healing methods, such as the vascular tube method, automatic self-healing, and intrinsic self-healing. It was noted that the vascular self-healing system typically activates on its own, but it can be difficult to properly position and safeguard it from premature failure during processing. However, the intrinsic method may not provide a dynamic healing experience.However, the team's research has uncovered that the inclusion of self-healing agents has the potential to enhance the post-impact characteristics of structural composites, representing a promising advancement. In their study, Coope and Wass [5] examined the use of metal triflates as catalytic curing agents in self-healing fiber-reinforced polymer composite materials. Their research focused on the application of self-healing techniques for Aerospace-grade FRP composite materials. This involved injecting EPON 828 and Lewis-acid metal triflate catalysts to enhance the material's healing properties. After implementing these SHAs, they noticed a minimum healing efficiency of 26%, which was higher than that of the commercial-based EPON 828/DETA system. They fabricated DCB test specimens with 0.5mm microvascular channels to create a network for delivering SHAs to damaged regions in the material. Their research also found that the type and loading of the catalyst played a significant role. The E25 Sc test specimens successfully achieved a minimum healing efficiency of 129% by injecting a pre-mixed solution at 45 8C, resulting in complete recovery of fracture toughness. Ultimately, achieving autonomous curing was a primary goal of this self-healing system. Therefore, curing at room temperature resulted in a minimum healing efficiency of 113% for this particular system. An improvement of 30% in healing efficiency was observed when healing at a temperature of 80 8C, as compared to healing at lower temperatures. The most optimal healing efficiency was attained by increasing the concentration of the catalyst in E25 Sc, which was cured at a temperature of 45 8C. The outcome was a significant 176% improvement in load recovery and an impressive 352% increase in fracture toughness recovery. In addition, a delivery method that operates autonomously was achieved by combining separate solutions of Sc (OTf)3-EPA and EPON 828 through parallel vacuoles. This method resulted in a complete load recovery and a fracture toughness of 88% at the start of delamination.

A study conducted by Melchior Das [5] focused on researching self-healing composites for aerospace applications. The study found that incorporating microcapsules, vascular networks, dissolved thermoplastics, and reversible interactions in polymer matrix composites can enable them to possess self-healing capabilities. In addition, self-healing composites have proven to be highly effective in tackling issues related to fatigue and impact resistance. They also have the ability to restore corrosion and barrier properties once they have healed. Applications in the aerospace sector involve a wide range of components and materials, such as fuselage and aerostructures, engine blades, combustion chambers, anticorrosion coatings, smart paints, and impact-resistant space structures.

Agarwal Goyal [6] conducted research on the practical uses of self-healing polymers, such as in spacecraft and road construction. The study revealed significant enhancements in the crack

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properties of stressed structures when self-healing polymers were utilized in space and construction applications. The self-repairing mechanisms also enhance the longevity of the material. Nevertheless, the impact of environmental factors such as temperature, pressure, and light presents a set of challenges that require meticulous attention. Their research suggested the need for additional investigation into performance properties such as cracking at low temperatures, rutting, and self-healing ability. Furthermore, it is crucial to further develop cutting-edge healing techniques and delve into the realm of emerging polymeric materials. However, more advancements are necessary as this study is still ongoing.

Chavan Kadam [7] examined the benefits and drawbacks of self-healing techniques and explored their practical application. It was determined that chemical fabrication methods are more efficient, although they can be challenging to implement for precise healing in physical processes. Self-healable nanocomposite structures can be created using stereolithography, a 3D printing technique. This involves combining ultraviolet curable resin with a solvent that contains anisole/poly-methyl methacrylate (PMMA)-filled urea-formaldehyde microcapsules. Self-healing hydrogels and supramolecular networks formed by hydrogen bonds play a crucial role in the medical field. Self-healing structures have a wide range of applications in various fields such as aerospace, biomedical, robotics, fluid mechanics, flexible electronics, and tissue engineering. Self-healing structures have enhanced fatigue resistance, making them highly valuable in aerospace applications. Autonomic self-healing hydrogels are also discussed here, mainly used for biomedical applications such as biosensors, tissue engineering, and drug delivery. The review also covered encapsulation techniques and self-healing hydrogels for biomedical applications. Finding the right balance between healing percentage, healing efficiency, and mechanical properties post-healing remains a formidable challenge.

Paolillo, Bose [6] conducted research on Intrinsic Self-Healing Epoxies in Polymer Matrix Composites (PMCs) for Aerospace Applications. The review discusses various self-healing epoxies, both as standalone materials and as matrix phases in composite materials. It provides a detailed analysis of their repair mechanisms, the testing methods used to assess their healing efficiencies, and their potential benefits for aerospace applications. The review initially emphasized physical methods of healing, which were developed in the early stages of this field of study, but later shifted towards more contemporary approaches involving chemical processes. It seems that the latter option has shown more promise. Designing self-healing epoxy formulations involves taking into account various factors, such as the chemical structure of the polymer backbone, its chain flexibility, and the quantity and characteristics of the reactive sites responsible for healing. In this review, a wide range of chemistries have been discussed. However, one key concept stands out regardless of the specific chemistry used: for healing to occur, it is essential that local reversibility, which involves bond forming-breaking reactions, happens much faster than global processes such as polymer flow and macroscopic deformation. This is crucial to prevent the material from undergoing total deformation or shape loss before healing can take place. Their review also found that, even in situations where recycling is not possible, reprocessing can offer significant economic savings and waste reduction. For instance, in certain cases, composite parts can be reshaped and components can be welded together using the strong adhesion properties of epoxies. Complex aerospace composite geometries can be assembled using more cost-effective methods. Instead of relying on long and expensive manufacturing techniques like autoclave, flat panels can be reshaped and chemically joined, making the production process easier and more affordable.

Coope, Turkenburg [7] conducted research on novel Diels-Alder-based self-healing epoxies for aerospace composites. Their research centered on the integration of a traditional epoxy amine system with furfuryl and maleimide functional groups through a two-step process. The aim was to minimize unwanted side reactions while finding the optimal concentration of a cross-linker with thermo-reversible binding properties. This delicate balance was crucial in achieving both thermoset and thermoplastic behaviors, ultimately leading to enhanced self-healing capabilities. In the realm of self-repair technologies, it is advantageous to have an inherent self-healing system. This system can be strategically placed in areas prone to damage, such as skin-stringer runouts, ply drops, and around drilled holes, which are common in aerospace structures that bear heavy loads. The study examined the performance of furan functionalized epoxy resins with different amounts of bismaleimide using a specific test specimen geometry. The focus was on the mechanical and self-healing properties. Two different forms, a thin film and a bulk material, were assessed to consider how they could be integrated into fibre-reinforced polymer (FRP) composites in the future. The 20-pph bulk material derivative exhibited the highest healing efficiency in terms of the obtained initial load value. The polymers achieved consistent multiple healing cycles when heated at 150 °C for 5 min. This novel explores the potential of DA material for FRP composites, as initial studies have demonstrated successful coextrusion with reinforcing fibers to create standalone films and dry fiber impregnation.

Zamal, Barba [8] conducted research on enhancing the electro-mechanical properties of self-healing composites by incorporating carbon nanotubes through microencapsulation. They were able to successfully achieve microencapsulation of multi-walled carbon nanotubes suspended in a 5-ethylidene-2-norbornene (5E2N) self-healing monomer, into poly melamine urea formaldehyde shells through in situ polymerization. The size of the microcapsules, their distribution, and the integrity and thickness of their shell walls were analyzed using optical and scanning electron microscopy. Microscopy and spectroscopy analyses confirmed the presence of carbon nanotubes (CNTs) within the core liquid content, as well as their release upon breaking. Thermogravimetric analysis and differential scanning calorimetry revealed that the presence of a small amount of CNTs inside the microcapsules did not have a notable effect on the thermal stability of the system. When CNT/5E2N microcapsules are added to polymer composites, the mechanical and electrical properties of CNT-based self-healing materials can be restored up to 80%. This makes them a great choice for aerospace applications.

Zhu, Cao [9] conducted research on the synthesis of UV-responsive self-healing microcapsules and their potential application in aerospace coatings. They successfully developed a coating that utilizes UV-responsive microcapsules to repair in-orbit damage. UV-responsive microcapsules with an inner polymeric shell that can be quickly degraded by the outer pure TiO_2 shell under UV radiation were created through UV-initiated polymerization of Pickering emulsions. These microcapsules were then incorporated into silicon resin matrices. When damaged, certain microcapsules can rupture due to external force. Subsequently, the intact microcapsules surrounding the affected areas will degrade under UV radiation. This process allows the release of encapsulated healing agents, ultimately leading to crack repair. This system demonstrates enhanced agent release capabilities through a dual release mode, resulting in more effective delivery of agents compared to conventional crack repairing systems. In addition, the harmful effects of UV radiation in space can be transformed into beneficial ones, making it potentially useful in aerospace coatings.

Benazzo, Rigamonti [10] conducted a thorough examination of fracture mechanics methods for characterizing self-healing and healable composites. After extensive testing, it was determined that all methods for characterizing the fracture toughness of composites have their own set of advantages and disadvantages, particularly when it comes to self-healing and healable composites. Thus, selecting a specific test becomes challenging when dealing with a new material that exhibits unpredictable behavior and lacks sufficient research for result comparison.There are significant disparities in the healing efficiency when comparing similar materials tested using different methods. As mentioned previously, the fracture toughness determined by mode I and mode II fracture should exhibit differences. However, the healing efficiencies based on fracture toughness should not vary significantly.

Kausar, Ahmad [11] conducted research on advancements and aerospace applications of self-healing nanocomposites. The self-healing behavior of the nanocomposites is influenced by various factors, including microphase separation, interactions between the matrix and nanofillers, and the diffusion of polymer and nanofillers. In addition, self-healing can be accomplished using healing agents like nano-capsules and nanocarbon nanoparticles. The self-healing mechanism operates through physical or chemical interactions. Self-healing nanocomposites have been utilized in the creation of various structural components, panels, laminates, membranes, coatings, and more, allowing for the recovery of damage to space materials. Furthermore, it was determined that the addition of nanoparticles has enhanced the performance properties of self-healing materials. Advanced healing techniques have been proposed in literature studies to go beyond the intrinsic and extrinsic mechanisms and address the challenges in fabricating and enhancing the performance of self-healing materials.

Teoh, Chia [12] conducted research on a self-healing composite material designed for use in the structural components of an aircraft. Through their research, it was determined that the composite had the ability to heal even when damage was detected, even with the addition of double-layer self-healing agents. The flexural strength results indicate that a notable portion of the strength is regained through the use of the self-healing agent contained in the hollow glass capillary tubes. After conducting the flexural 3-point bend test on the prepared samples, it was found that the doubled layer healed hollow fibre laminate, which underwent a healing regime of 3 weeks, exhibited a significant increase in strength of 27% compared to the damaged baseline laminate.

In a study conducted by Orfanidis and Kosarli [13], they focused on investigating the structural integrity and healing efficiency of composite materials that utilize micro-capsules. Through the use of 1 H NMR relaxometry, they were able to establish a correlation between the signal intensity and the amount of encapsulated self-healing agent. This groundbreaking research marked the first time in literature that the quantity of the encapsulated self-healing agent mass was confirmed non-destructively using 1 H NMR spin-spin relaxation techniques. The study specifically examined urea-formaldehyde (UF) microcapsules of varying diameters that contained an epoxy healing agent. Reducing the capsule diameter increases the amount of self-healing agent, but it also makes the capsules more fragile and prone to failure due to the reduced shell mass. Through NMR experiments conducted during thermal cycling simulating flight conditions, we have observed variations in microcapsule integrity based on their size. Through experimentation, we have confirmed that the microcapsules with the most sensitive shells are those with diameters of 147 nm and 133 nm. These particular microcapsules are widely utilized in self-healing systems. At last, we successfully obtained identical results by utilizing a portable NMR spectrometer that we developed ourselves. This highlights the immense potential of NMR relaxometry as a highly effective non-destructive evaluation tool for the microcapsule production line.

Tetteh, Mensah [14] conducted research on the repeated healing of damage caused by low-velocity impacts in orthogrid-stiffened sandwich panels. They used a pin-guided dry-weaving technology to create sandwich panels and assessed their impact responses through low-velocity impact testing. After the initial impact, a notable failure mode was the occurrence of transverse cracking in the SMV matrix within the sandwich core. After the first healing cycle, the healing efficiency was determined to be 76.5% based on the crack initiation energy (CIE). Even after the second healing cycle, the healing efficiency remained above 72%. Through conducting low-velocity impact tests, it was observed that the impact resistance of the pure SMV core was greatly improved when reinforced with a grid skeleton. Specifically, the crack initiation energy and peak load saw a substantial increase of 64.0% and 169.0%, respectively. The findings also indicate that a reduced bay area results in increased impact resistance. Featuring the benefits of repeated crack healing, enhanced impact tolerance, and a shape memory effect.

Perin, Mahmood [15] conducted research on innovative epoxy/cyclic olefin copolymer/carbon structural composites that possess electro-activated self-healing properties. Three different laminates were prepared, which included neat EP/CF and two composites with 4 wt.% and 8 wt.% of COC in the form of a jet-spun network as a healing agent. The implementation of COC mesh resulted in a 26% decrease in flexural stress and a 50% reduction in interlaminar shear strength. Mode I interlaminar fracture toughness (GI) was assessed and specimens were repaired at 110C using resistive heating produced by an electrical current passing through the samples. The laminates with 8wt% COC demonstrated healing efficiencies of 9.4% and 33.7%, respectively, which were evaluated by comparing the maximum load (PMAX) of the virgin and healed samples. Fractography analysis revealed the lack of adhesion between the COC mesh and EP matrix. Additionally, some COC microfibers were found to be trapped within the epoxy matrix, impeding their movement within the crack zone. As a result, the healing capability of the prepared laminates was limited.

Wen, Luan [16] conducted research on the self-healing and de-icing capabilities of thermoplastic polyurethane composites reinforced with graphene-carbon nanotubes, which are activated by electric current. For their research, they prepared composites of thermoplastic polyurethane (TPU) reinforced with modified graphene (G) and carbon nanotubes (CNTs). The goal was to enhance the functionality of the composites, such as self-healing and deicing, by improving the interfacial properties of the graphene-polyurethane composites. Initially, the composites with varying percentages of graphene (1%, 3%, 5%, and 7%) were prepared using the solution blending method. Next, the researchers examined the self-healing behaviors of the composites with pre-existing cracks that were caused by electrical currents. At last, the tension tests were conducted on both the virgin composite and the healed composite films to evaluate the self-healing properties of the CNT-G/TPU composite films. In addition, the study examined the thermogenic effects of a composite material made of G-CNT/TPU with varying amounts of graphene at different voltages. The research also yielded data on the relationship between voltage and temperature. The results indicate that the surfaces of the composite films containing 1 wt% graphene exhibit minimal temperature fluctuations and lack the ability to repair current. As the graphene content increases, the composite film shows a gradual rise in temperature beyond a certain point. Additionally, the repair effect of the film also improves, with the G-CNT/TPU composite film containing 7wt% graphene achieving a repair efficiency of 95%. It also accomplishes energization and de-icing functions through its conductive properties.

Zhao, Yan [17] conducted research on the wear and corrosion resistance of self-healing epoxy coatings filled with a unique assembly of polysulfide double-walled microcapsules, incorporating polydopamine-modified graphene oxide. Through their research, they created a self-healing coating that has exceptional resistance to wear and corrosion. This was achieved by developing a unique double-walled microcapsule filling epoxy resin coating, where graphene oxide was assembled onto the outer shell layer of polysulfide through polydopamine modification. The surface of the microcapsules that were prepared had a rough texture, with a particle size of 60–70 μm and a wall thickness of 2–3 μm. The double-walled microcapsule filling composite coating demonstrated improved mechanical performance and thermal stability, thanks to its enhanced dispersion and compatibility. The EP coating filled with 10.0 wt% microcapsules exhibited significantly lower average friction coefficient and wear rate compared to the pure EP coating. After 7 days of immersion, the coating exhibited an impedance value and low-frequency impedance modulus that were significantly higher than those of pure EP. After 72 hours, the self-repair process became more apparent due to the improved surface hydrophobicity. The self-healing EP coating's exceptional wear and corrosion resistance can be attributed to the synergistic mechanism of the double-walled microcapsules.

Raimondo, De Nicola [18] conducted research on self-repairing CFRPs for use in structural aerospace applications. They created a self-repairing system using a chemical reaction of encapsulated cyclic olefins, which was initiated by Hoveyda-Grubbs' first-generation catalyst. In this work, the self-healing resin is infused into a carbon fibre dry preform using an innovative bulk film infusion technique. This technique has enabled the minimization of filtration effects through improved compaction and reduced resin flow paths. Infrared spectroscopy is a valuable tool for identifying metathesis products and assessing catalyst activity in the self-healing panel following damage. The manufactured CFRPs were subjected to hail and drop tests to evaluate their damage resistance. The research revealed that the manufactured panels have the ability to heal themselves. When damaged, they exhibit catalyst activity and produce metathesis products, as indicated by the presence of an infrared peak at 966 cm−1. The damage response of CFRPs, as observed in the requirements for designing a composite material fuselage to withstand hail impact, is highly satisfactory. The results are highly promising and provide a strong foundation for implementing this new technology in self-healable fibre-reinforced resins for aerospace applications.

Guo, Jia [19] conducted research on UV-Triggered Self-Healing of a Single Robust SiO_2 Microcapsule Based on Cationic Polymerization for Potential Application in Aerospace Coatings. Their research centered on developing a cutting-edge SiO_2 microcapsule self-healing system that could be used in aerospace coatings. This system is activated by UV light and utilizes cationic polymerization, making it highly durable and reliable. Through a combined interfacial/in situ polymerization process, the epoxy resin and cationic photoinitiator are effectively encapsulated within a single SiO_2 microcapsule. This is achieved by carefully matching the solubility parameters of the active healing species and the SiO_2 precursor. The SiO_2 microcapsule exhibits excellent solvent resistance and thermal stability, particularly demonstrating remarkable resistance to thermal cycling in a simulated space environment. Furthermore, the epoxy resin demonstrates an impressive curing efficiency of up to 89% within just 30 minutes. Additionally, the scratches in the epoxy matrix are visibly filled, showcasing the outstanding UV-induced healing capabilities of SiO_2 microcapsules. This can be attributed to the high concentration of healing species within the capsule, reaching up to 87% by weight. The healing chemistry is based on a precise stoichiometric ratio of the photoinitiator and epoxy resin, set at 9/100. Furthermore, the UV-triggered cationic polymerization mechanism used in this healing chemistry is not affected by oxygen, making it

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highly convenient for potential use in spacecraft by easily embedding a single SiO_2 microcapsule.

II. METAL MATRIX COMPOSITES (MMC)

There are four primary categories of composite materials that are classified based on the materials used for their production. These categories include Metal Matrix Composites (MMCs), Ceramic Matrix Composites (CMCs), Polymer Matrix Composites (PMCs), and Carbon Matrix composites (also referred to as carbon composites) Figure 2. MMC's possess several advantages compared to other composites. They have the ability to withstand high temperatures, moisture, radiation, and zero outgassing in vacuum conditions. Additionally, they exhibit excellent thermal and electrical conductivities, as well as improved mechanical properties [20]. MMCs consist of a ductile metal or alloy matrix that is reinforced with various metal, non-metallic, or organic compounds [21]. Implanting reinforcements into the metal matrix is essential for producing MMCs. High-performance reinforcement materials are utilized to enhance the characteristics of the matrix material, including specific strength, specific stiffness, wear resistance, exceptional corrosion resistance, and a high elastic modulus [22]. Out of the matrix materials available for MMCs, Al and Mg are the most commonly used. Magnesium-based composites have garnered considerable interest because of their appealing mechanical properties compared to monolithic alloys.

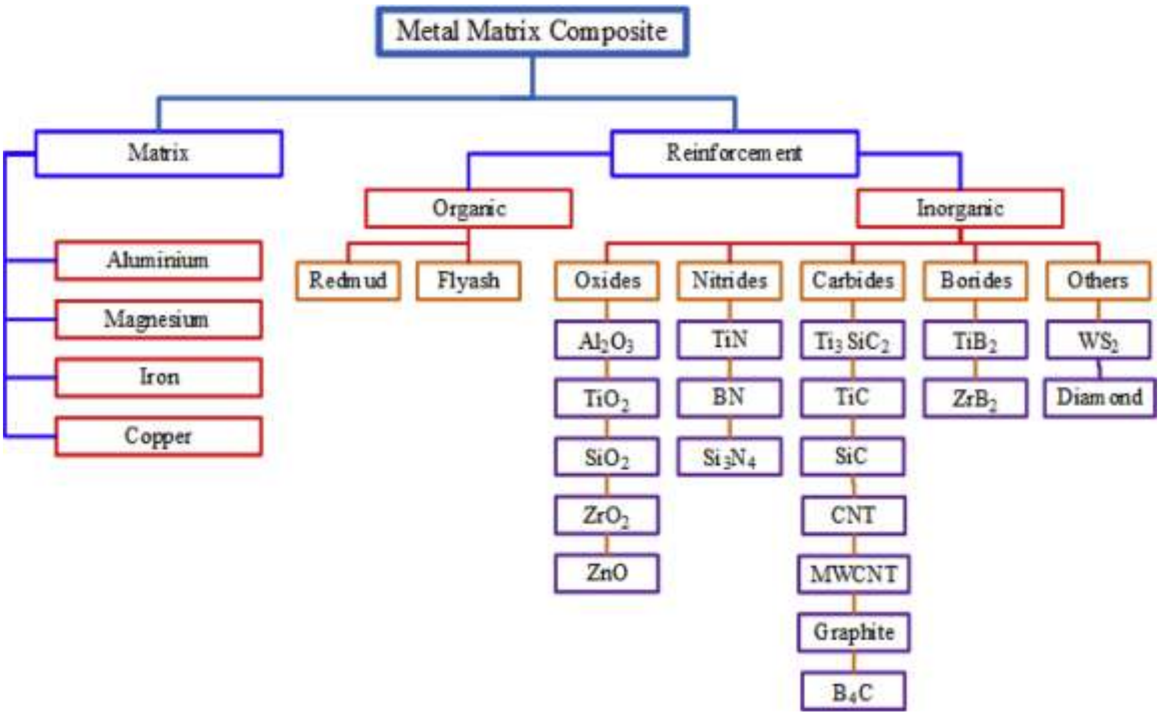

Figure2: Showcases the utilization of different matrix and reinforcement materials in the production of MMCs[23].

2.1 ALUMINIUM COMPOSITE MATERIALS (AMC)

Currently, the melt infiltration process is one of the commonly used methods for preparing particle-reinforced metal matrix composites. [24], spray deposition. [25], utilizing the powder metallurgy technique. Using the in situ reaction method, a reaction was conducted [26]. [27] and so on. Self-healing in the metallic system is an exciting and rapidly developing field in material science and engineering. Given the limited availability of natural resources, it is important to investigate methods that can effectively improve the sustainability of a component. Self-recuperation is an emerging field in the realm of material science and engineering. Inspired by the resilience of nature and the endless possibilities of modern innovation, researchers are striving to incorporate these qualities into the design of materials. The design philosophy revolves around a material that can withstand damages like cracks, wear, and corrosion, while also having the ability to self-heal the damage, including micro and macro cracks, and restore the functionality of the product to over 70% of its initial level. [29] Table 1 displays the different uses of AMCs in brake rotors, while Figure 3 and Figure 4 illustrate single-calliper sliding pistons.

Table 1, shows the various applications of AMCs in brake rotors Figure3 and single-calliper sliding pistonsFigure4.

Table 1: Application of Composite Systems[30]

Composite System	**Components**	**Area**
$Al/SiC/Al_2O_3$	Piston, disc brake, fastener fan exit guide vane, rotating blade Piston, Hydraulic actuators	Automotive, Aerospace[31, 32]
$AlSi_7Mg2Sr0.0_3/SiCp$	Bearings, piston	Automotive[33]
Al/Gr	Cutting tools, machine	Automotiveand manufacturing [34]
Al/Zr /Al/SiCW	Connecting rod, Sprockets	Automotive[35, 36]
Cu/Gr	Current Collectors	Automotive [35, 36]
Al/Al_2O_3-CF	Engine block	Automotive [35,36]
Al-Al_2O_3	Reactor core	Nuclear [37]

Figure 3:AMC brake rotors[38]

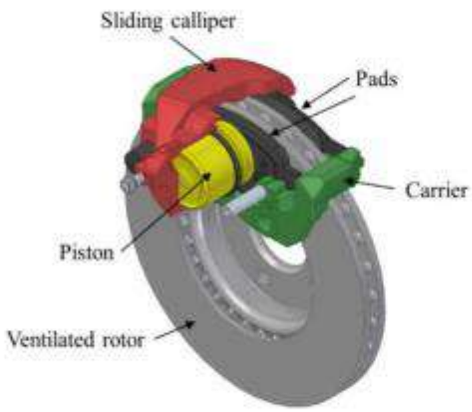

Figure 4:AMC single piston sliding caliper disc brake[39]

Research around the world is dedicated to improving the performance and longevity of engineering materials. Traditional materials are being replaced by stronger alloys and composites that offer better mechanical and thermal properties. Among these, aluminium matrix composites (AMCs) are particularly popular and extensively studied due to their ease of production, desirable properties, and convenient post-fabrication heat treatment options. AMCs have impressive properties such as exceptional strength, stiffness, and resistance to corrosion. AMCs are manufactured using two primary methods: stir casting and powder metallurgy. These techniques are utilized in various industries such as automotive, aerospace, recreation, military, and marine sectors[43].

2.1.1 Stir Casting Method

Stir casting is a highly effective method for manufacturing Metal Matrix Composites (MMCs) due to its straightforward process, established track record, cost-effectiveness, and ability to produce large quantities. With the increasing complexity of engineering requirements, there is a growing demand for advanced materials that can meet these needs. Metal matrix composites have become a viable solution to address these requirements. These composites bring together various materials to optimize their strengths and minimize their weaknesses. A class of composites that researchers have utilized is Metal Matrix Composites (MMC), which has been used to produce a specific type of aluminium metal composite called AMC. Utilizing these cutting-edge composites has the potential to completely transform engineering applications, providing unmatched properties and performance. The vortex technique, also known as stir casting, is a highly popular method for creating aluminum matrix composites (AMCs) such as SiC/Al_2O_3. This method entails incorporating reinforcements into the molten metal and subsequently casting the mixture into the desired shape. It is essential to remove any gases from the melt prior to adding the reinforcements to prevent any potential reactions with atmospheric oxygen. Utilizing a rotor, a vortex is created within the liquid metal to achieve a uniform distribution of the reinforcements. At the same time, a gas is injected into the mixture to carry the reinforcements[61-65]. The resulting slurry can be shaped using traditional casting techniques such as permanent mould casting, squeeze casting, and sand casting. Nevertheless, this method may result in the occurrence of gas entrapment, slag in the melt, high porosity, micro-defects, undesired chemical reactions between the matrix and the reinforcements, and inadequate wetting between the matrix and reinforcements. These factors can have a detrimental effect on the mechanical properties of the composite. In order to tackle these issues, adjustments need to be made to process variables such as the duration of melt stirring, the temperature at which the melt is held, the temperature of the molten metal, and the selection of matrix and reinforcement materials. Figure 5 illustrates a depiction of the stir-casting technique, while Table 2 provides a comprehensive list of the pros and cons associated with this method.[66-69]

Table 2 Advantages [70]and disadvantages [71, 72] of the squeeze casting method

Advantages	**Disadvantages**
Simple and flexible	Difficult to achieve homogeneity
Economical for mass production	Possibility of reaction between matrix and reinforcement
Good matrix-reinforcement interface	High porosity in composite and poor wetting

Recently, there has been a noticeable trend towards the use of composite materials in material development. This shift has been influenced by the growing need for structural materials that are both lightweight and high-performing, while also being cost-effective. AMCs have become increasingly popular in industries like aerospace and automotive because of the numerous advantages they offer. These include improved performance, cost-effectiveness, and a reduced environmental footprint [31,73].Existing literature primarily focuses on the utilization of 200, 600, and 700 aluminium matrixes reinforced with SiC particles to enhance their strength properties. However, there is a lack of adequate information regarding the reinforcement of "Al_2O_3" particles in 7xxx aluminium matrix. The 700 series aluminum matrix typically consists of a combination of copper, zinc, and magnesium. Thus, the current study aimed to examine how the inclusion of elemental metal,

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specifically Cu-Zn-Mg, in an aluminium matrix impacts the mechanical properties of stir casting of aluminium composite materials. These composites are reinforced with alpha "Al_2O_3" particles and are produced using a straightforward foundry melting alloying and casting method. Age-hardening treatments were also conducted to examine the ageing response of the aluminum matrix on strength, ductility, and hardness. The experimental results suggest that aluminium matrix cast composite can be produced using the traditional foundry method, resulting in excellent strength and ductility. In a study by Vijaya, Kumar, it was observed that the 7000 series of aluminium is widely used in various industries such as military, defense, marine, automobile, radiation shielding, aviation, and high temperature applications due to its exceptional strength at elevated temperatures. The AA7075 alloy is highly regarded for its exceptional strength and excellent performance in both low and high-temperature environments. This is due to the presence of zinc, which plays a crucial role in enhancing the material and mechanical properties of the alloy. Various particulate reinforcements can significantly improve the mechanical and thermal characteristics of AA7075 MMCs. AA7075 is an excellent matrix material that is well-suited for a wide range of applications, particularly when toughness is the main focus at high temperatures. The liquid route stir casting method is a cost-effective and efficient technique that guarantees even distribution of reinforcement in the alloy. This is achieved through a setup method, as illustrated in Figure 5. This is due to the stirring action that guarantees the even distribution of the particulate reinforcement within the matrix alloy. It enhances the interfacial bonding between the reinforcement and matrix. By utilizing this approach, one can achieve the lowest possible percentage of porosity and dislocation density. Magnesium is added to the melt to improve the wettability between the matrix and reinforcement material. The properties of the cast product are determined by various factors such as the melting temperature, stirring time, stirring temperature, stirring speed, reinforcement preheating temperature, type of matrix and reinforcement, wettability, inert atmosphere, and pouring temperature. Titanium (Ti) is a highly desirable material that exhibits exceptional resistance to creep and fatigue stress, even at high temperatures. The primary objective of incorporating nano-sized titanium into the aluminium metal matrix alloy is to enhance its mechanical strength, ductility, and tribological properties for both low and high-temperature applications. Based on the literature, it is clear that titanium is a highly corrosion-resistant material that finds great use in naval applications like propellers, shipbuilding, structures, and military and defense applications. Niobium possesses excellent resistance to high temperatures and exhibits a malleable nature, characterized by its body-centred cubic (BCC) structure. NbC was commonly used in cutting tools. At cryogenic conditions, niobium exhibits superconductivity. It exhibits superior formability, weldability, toughness, and strength characteristics. NbC exhibits exceptional physico-mechanical properties, including a high melting point, excellent electrical conductivity, and remarkable hardness, resulting in superior thermal resistance. By incorporating reinforcement particulates into the MMC material, the dislocation density and work hardening are increased, resulting in improved mechanical behavior of particle-reinforced MMCs. Nevertheless, the increase in this particular type of composite is greater compared to another type, thanks to the Hall-Petch effect and Orowan strengthening mechanism.

Figure5: Stir casting set-up.[76]

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The effects of CNT, Mg, and mechanical stirring on the hardness and UTS of the MWCNT-A356 composite were investigated by Hanizam and Salleh [77]. The fabrication parameters were fine-tuned using the Taguchi method. The composite was fabricated using LM processing, and there was some agglomeration of MWCNT particles observed in high-concentration samples. Thixoforming and MT6 heat treatment significantly improved the hardness and UTS values, resulting in a remarkable increase of 76.3% and 108.4%, respectively. The duration of stirring had a significant impact on enhancing the mechanical properties. In a study conducted by Zhu and Jiang [78], they explored the combination of stir casting and squeeze casting techniques for producing self-healing aluminium composite materials. Their research, titled "Microstructure and mechanical properties of SiCnp/Al6082 aluminum matrix composites prepared by squeeze casting combined with stir casting," delved into this topic. Through their research, it was determined that the distribution of SiCnp in the 6082-aluminium matrix alloy was consistent when using stir casting. By incorporating the SiCnp, a significant improvement was observed in the microstructure of the 6082-aluminum alloy. The addition of SiCnp resulted in a remarkable 30.55% grain refinement compared to the 6082-aluminum alloy without SiCnp. The ultimate tensile strength, yield strength, and elongation of the SiCnp/Al_60_{82} aluminium matrix composites were significantly improved compared to the 6082-matrix alloy without the SiCnp. Specifically, there was an increase of 8.92% in ultimate tensile strength, 12.16% in yield strength, and 12.60% in elongation. Following the SC process, there was a notable enhancement in the compactness of the SiCnp/ Al6082 composites, resulting in a finer grain structure. The SiCnp/Al6082 composites fabricated by the SC showed significant improvements in ultimate tensile strength, yield strength, and elongation compared to the 6082-aluminium alloy obtained by gravity casting (GC). The increases were 29.81%, 43.18%, and 226.28% respectively. Utilizing a mechanical stirring method, as depicted in Figure 6. Around 2 kg of raw materials were melted at a temperature of 760 ℃ in the crucible. Once the 6082 aluminium alloy materials were completely melted, the melt was maintained at a temperature of 740 °C. To refine and eliminate slag from the aluminium alloy liquid, degassing was performed by bubbling argon gas for a duration of 5 minutes. Finally, any surface scum was removed using a slagging spoon. At a temperature of 730 °C, the pre-treated SiCnp were introduced into the melt using mechanical stirring to enhance the dispersion of the SiCnp. The stirring speed was set at 300 rpm. After the addition of all the SiCnp, the stirring was continued for 30 minutes, as per the findings of Zhang, Zhang [79].

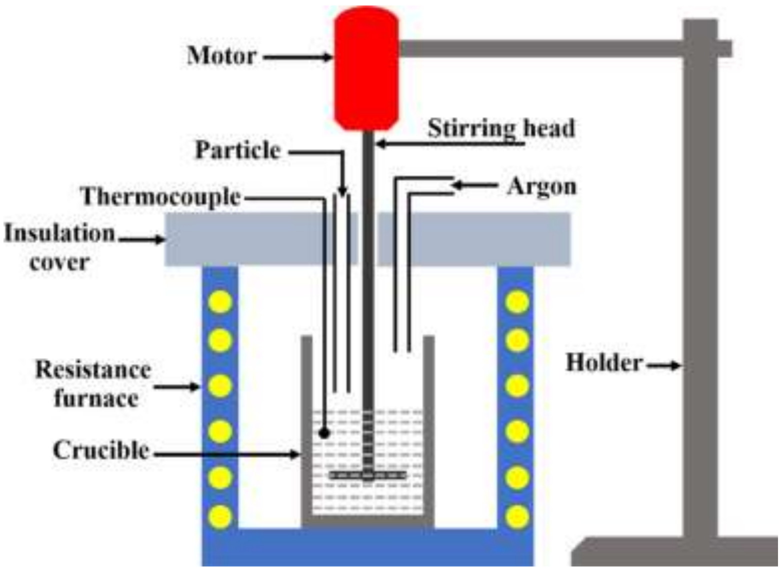

Figure 6: Sketch of fabrication of the SiCnp/Al_60_{82}aluminium matrix composites using stir casting.[78]

Adding B_4C to an AA6061-B_4C composite system may not always yield the desired improvements in its properties. This is a result of problems associated with the incorporation,

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distribution, and interfacial wetting that occur during the stir-casting process. Nevertheless, ultrasonication offers an alternative method to induce microstructural changes that have the potential to enhance the properties. Through this study, it was discovered that a B_4C content of 4wt.% was effective in achieving a precise distribution of B_4C and enhancing the microstructure. The specific ultimate and compressive strengths showed a significant improvement of 36.32% and 43.92%, respectively. Additionally, the specific Vickers and Brinell hardness experienced a notable increase of 53.41% and 50.89%, respectively[80].

2.1.2 Powder Metallurgy

It has been noted that the addition of particulate reinforcement to aluminium alloys is done with the primary goal of enhancing mechanical properties, including modulus, strength, and creep resistance, even under high temperatures. Furthermore, the material's wear resistance also experiences an increase. The properties of a material are greatly influenced by the type, size, quantity, and distribution of reinforcements incorporated into it. Obtaining the desired range of properties necessitates a meticulous level of dispersion, seamless integration of the hard material into the metal matrix, and the establishment of a suitable interface condition.[82, 83]. Particle size is a crucial factor in determining how reinforcements are distributed and dispersed. Finer particles generally exhibit better embedding quality and are less likely to break during powder metallurgical processing or post-deformation[84-86]. AMCs can be produced using two different methods: the powder route or the melting route. On the other hand, the powder route offers several benefits. Given the lower temperatures involved, there is a lack of chemical reactions between the matrix and reinforcements, which typically occur in the molten state[26, 83, 87]. As the particle sizes of the reinforcement components decrease, this aspect becomes more and more crucial. In the first step, highly dispersed composite powders are produced, which are then compacted in the second step. High energy milling (HEM) is an effective technique for producing composite powders[88-90].

Fundamentally the steps in PM are mixing, compaction in a die or mould and sintering in a furnace for consolidation [91] and secondary operation might be applied for special behaviour or dimensional precision [92]as indicated inFigure7.

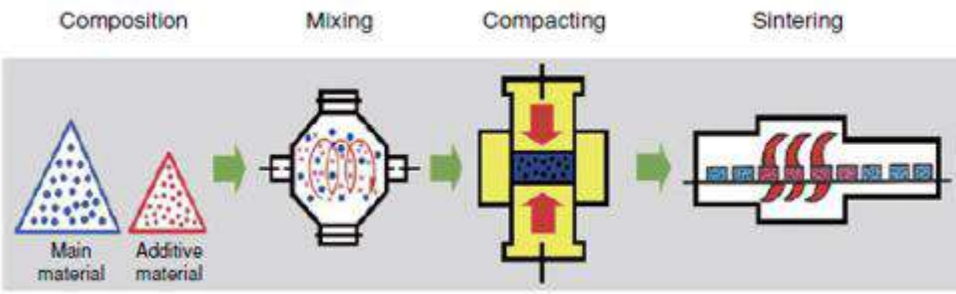

Figure 7: Powder metallurgy process steps[93]

The thorough dispersion of the reinforcing particles within the matrix leads to improved mechanical properties in PM. There is a clear relationship between the size, amount, type, and surface nature of reinforcement and the properties of the composite produced by PM. Research has shown that when the reinforcement is scaled down to the nano level, the properties of the composite tend to improve. However, this also makes the fabrication process more complex.

Nestler, Siebeck [81] conducted a study on Powder Metallurgy of Particle-Reinforced Aluminum Matrix Composites (AMC) using High-Energy Ball Milling. Their study centered around the use of spherical powder made from the aluminium alloy AA2017 (grain fraction > 100 µm) as the matrix material. Submicron and micron-sized SiC and Al_2O_3 powders were selected as reinforcement particles, with volume percentages ranging from 5 to 15%. The high-energy milling process was carried out in a Simoloyer mill (Zoz). The milling process took approximately 4 hours. A compact material was produced by utilizing hot isostatic pressing (HIP). The extrusion process creates semi-finished products with various geometric shapes. We will discuss the stages of composite powder formation during high-energy ball milling through metallographic studies. The SEM and TEM results reveal the microstructure of the compact composites achieved through HIP and

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extrusion techniques. This study examines the dispersion and embedding of reinforcement particles and matrix/reinforcement interfaces. We will discuss common occurrences such as the presence of ferrous contaminations due to the abrasion of steel balls and the formation of the spinel phase $MgAl_2O_4$ during the powder-metallurgical processing that follows. The semi-finished product demonstrates excellent particle dispersion and minimal microporosity. There are no visible accumulations of the brittle phases or any microcracks at the interface between the reinforcement particles and the matrix. In their research, Mohapatra and Maity [97]. Examining the Synthesis and characterization of hot extruded aluminium-based MMC developed by powder metallurgy route, the study indicates that the enhanced mechanical and tribological properties can be attributed to the improved density and excellent bond strength resulting from high compressive stress. For the thermomechanical treatment, they utilized a mathematically contoured cosine profiled die to ensure the prevention of product defects. The inquiry focused on the improvement of mechanical characterization, including density, hardness, compression test, and three-point-bend test. The wear behavior of the prepared AMCs was studied through a pin-on-disc wear testing method. The study involved investigating the two-body dry sliding wear before and after extrusion. Various parameters such as load (N), track diameter (mm), and RPM of the counter disc were varied to analyze their effects. A study was conducted to analyze the impact of hot extrusion on the mechanical and tribological properties of aluminium matrix composites (AMCs) that were produced using powder metallurgy techniques, double axial cold compaction, and controlled atmospheric sintering. The shearing of the graphite particles on the tribo surface serves as a solid lubricant, effectively reducing the rate of wear. Under more demanding loading and sliding velocity conditions, a combination of wear mechanisms was observed. Using powder metallurgy results in improved mechanical properties, thanks to the excellent wettability between the matrix and reinforcements, as well as a uniform microstructure with desirable phases in the composite. This paper investigates the impact of various powder processing factors, including milling time, milling speed, compaction pressure, sintering time, and temperature, on the mechanical properties of the AMC when incorporating different sizes and volumes of SiC and Al_2O_3. [30]. Purohit, Rana [98] Enhanced the strength of aluminum by incorporating SiC particles using a powder metallurgy technique. The powders were subjected to a process of mechanical alloying for a duration of 12 to 15 milling hours at a speed of 78 rpm. This was followed by cold isostatic pressing at a pressure of 600 MPa using a mold. Ultimately, they were compressed in a die with a force of 500 KN. The green compact was heated at 580 °C for 1800 seconds, followed by a temperature increase to 600°C for 2700 seconds. These steps led to a notable improvement in hardness, compressive strength, and tensile strength. The milled powder showed exceptional properties in comparison to the un-milled powder. In their research, O'Donnell utilized the traditional powder metallurgy technique to incorporate SiC particles of different sizes into AA6061. The mixture was compressed in a die using a precise pressure of 235 ± 5 MPa, at a controlled rate of 7 MPa/s. After going through the sintering process at specific temperatures and durations, the material displayed an interesting relationship between reduced SiC size and its mechanical properties. It was observed that a smaller SiC size led to an improvement in yield strength, but at the same time, it resulted in a decrease in toughness or ductility as the volume fraction of SiC increased. In addition, the distribution of the reinforcement was uniform across the matrix. In their study titled "Microstructural characterization and mechanical properties of functionally graded Al_20_{24}/SiC composites prepared by powder metallurgy techniques," Erdemir and Canakci [99] conducted a thorough investigation to analyze the mechanical properties of the workably graded Al_20_3-SiC composite. It was noted that the hardness of the composite showed a significant increase at SiC contents of 30% and 40%, but a decrease was observed when the SiC content was raised to 50% and 60%. It is important to highlight that the presence of high porosity in the composite material had a detrimental effect on its mechanical properties, resulting in a reduction in hardness. This discovery has important implications for the advancement of composite materials with precise mechanical properties. It is crucial to carefully evaluate the SiC content in order to attain the best possible material performance. Shaikh, Arif [100] conducted a study on the fabrication and characterization of aluminium hybrid composites. These composites were reinforced with fly ash and silicon carbide using the powder metallurgy method. The findings indicated that the augmentation in the quantity of fly ash and SiC led to an enhancement in both hardness and wear

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resistance. Nuruzzaman, Kamaruzaman [101] conducted a study on the impact of sintering temperature on the characteristics of composite materials made from aluminum and aluminum oxide. They produced AMC by strengthening aluminum with Al_2O_3 using traditional powder metallurgy techniques. The mixture was compressed with a force of 20 tons in a die, and then heated to sinter at two distinct temperatures of 550^0C and 580^0C. The density and compressive strength of AMC were influenced by the sintering temperature and the quantity of Al_2O_3.

Above, it is observed that as the number of reinforcements and sintering temperature increased the yield and hardness increased to an optimum point and suddenly decreased due to the high content of alumna and the increase in temperature. As shown in figure 8.

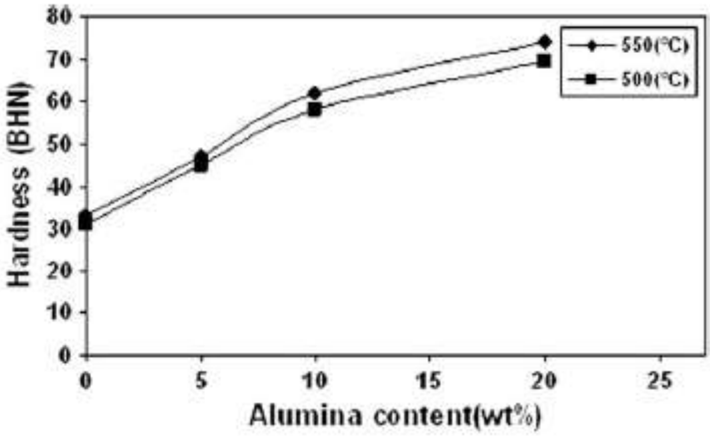

Figure 8:.Effect of Al_2O_3particle content and sintering temperature on yield stress and hardness [102]

III. CONCLUSION

Manufacturing techniques such as powder metallurgy, mechanical alloying and milling, microwave and spark plasma sintering, stir casting, spray-up and ultra-sonic assisted casting techniques are commonly used in producing advanced materials known as AMCs. Researchers from both academic and industrial fields have shown great interest in self-healing AMCs, leading to an increase in literature on the mechanical properties of these materials. However, it has been found that stir casting, one of the two major methods of producing AMCs, has been more extensively studied in the area of self-healing, while the powder metallurgy method has mostly focused on the mechanical properties of the composites produced.From the reviewed literature, it has been established that the hardness/compressive strength and tensile/ultimate tensile strengths of AMCs increase with the number of reinforcements, sintering time, temperature, compaction load, and reduction in size of the reinforcements. However, there is still a need for research to fully understand the impact of introducing self-healing agents through the powder metallurgy method on the pre- and post-healing mechanical properties of AMCs. This will help achieve the best mechanical properties of AMCs for application in aerospace industries.

REFERENCES

[1]. Rana, S. and R. Fangueiro, Advanced composites in aerospace engineering, in Advanced composite materials for aerospace engineering. 2016, Elsevier. p. 1-15.

[2]. JE, P.C., et al., Manufacturing challenges in self-healing technology for polymer composites—a review. 2020. **9**(4): p. 7370-7379.

[3]. Mobaraki, M., M. Ghaffari, and M. Mozafari, Self-healing polymers for composite structural applications, in Self-Healing Composite Materials. 2020, Elsevier. p. 33-51.

[4]. Chujo, Y., K. Sada, and T.J.M. Saegusa, Reversible gelation of polyoxazoline utilizing Diels-Alder reaction. 1990. **23**(10): p. 2636-2641.

[5]. Coope, T.S., et al., Metal Triflates as Catalytic Curing Agents in Self-Healing Fibre Reinforced Polymer Composite Materials. 2014. **299**(2): p. 208-218.

[6]. Paolillo, S., et al., Intrinsic self-healing epoxies in polymer matrix composites

(PMCs) for aerospace applications. 2021. **13**(2): p. 201.
[7]. Coope, T., et al., Novel Diels-Alder based self-healing epoxies for aerospace composites. 2016. **25**(8): p. 084010.
[8]. Zamal, H.H., et al., Recovery of electro-mechanical properties inside self-healing composites through microencapsulation of carbon nanotubes. 2020. **10**(1): p. 2973.
[9]. Zhu, Y., et al., Synthesis of UV-responsive self-healing microcapsules and their potential application in aerospace coatings. 2019. **11**(36): p. 33314-33322.
[10]. Benazzo, F., et al., A critical appraisal of fracture mechanics methods for self-healing and healable composites characterization. 2023: p. 107450.
[11]. Kausar, A., et al., Self-Healing Nanocomposites—Advancements and Aerospace Applications. 2023. **7**(4): p. 148.
[12]. Teoh, S., et al., Self-healing composite for aircraft's structural application. 2010. **24**(01n02): p. 157-163.
[13]. Orfanidis, S., et al., Structural integrity and healing efficiency study of micro-capsule based composite materials via 1H NMR relaxometry. 2023. **13**(1): p. 12189.
[14]. Tetteh, O., P. Mensah, and G.J.J.o.C.M. Li, Repeated healing of low-velocity impact induced damage in orthogrid-stiffened sandwich panel. 2023: p. 00219983231191299.
[15]. Perin, D., et al., Novel epoxy/cyclic olefin copolymer/carbon structural composites with electro-activated self-healing properties. 2023.
[16]. Wen, Z., Y. Luan, and Y. Li. Self-healing and De-icing Functions of Graphene-carbon Nanotube Synergistic Reinforced Thermoplastic Polyurethane Composites Induced by Current. in Journal of Physics: Conference Series. 2023. IOP Publishing.
[17]. Zhao, P., et al., Wear and corrosion resistance of self-healing epoxy coatings filled by polydopamine-modified graphene oxide assembly of polysulfone double-walled microcapsules. 2023. **177**: p. 107416.
[18]. Raimondo, M., et al., Self-repairing CFRPs targeted towards structural aerospace applications. 2016. **7**(5): p. 656-670.
[19]. Guo, W., et al., UV-triggered self-healing of a single robust SiO2 microcapsule based on cationic polymerization for potential application in aerospace coatings. 2016. **8**(32): p. 21046-21054.
[20]. Rajan, T., R. Pillai, and B.J.J.o.m.s. Pai, Reinforcement coatings and interfaces in aluminium metal matrix composites. 1998. **33**: p. 3491-3503.
[21]. Ekka, K.K., et al., Dry sliding wear characteristics of SiC and Al 2 O 3 nanoparticulate aluminium matrix composite using Taguchi technique. 2015. **40**: p. 571-581.
[22]. Kok, M.J.J.o.m.p.t., Production and mechanical properties of Al2O3 particle-reinforced 2024 aluminium alloy composites. 2005. **161**(3): p. 381-387.
[23]. Ramanathan, A., P.K. Krishnan, and R.J.J.o.M.p. Muraliraja, A review on the production of metal matrix composites through stir casting–Furnace design, properties, challenges, and research opportunities. 2019. **42**: p. 213-245.
[24]. Aghajanian, M., et al., The fabrication of metal matrix composites by a pressureless infiltration technique. 1991. **26**: p. 447-454.
[25]. Raju, K., S. Ojha, and A.J.J.o.m.s. Harsha, Spray forming of aluminium alloys and its composites: an overview. 2008. **43**(8): p. 2509-2521.
[26]. Torralba, J.D., C. Da Costa, and F.J.J.o.M.P.T. Velasco, P/M aluminium matrix composites: an overview. 2003. **133**(1-2): p. 203-206.
[27]. Du, X., et al., In situ synthesizing SiC particles and its strengthening effect on an Al–Si–Cu–Ni–Mg piston alloy. 2017. **695**: p. 1-8.
[28]. Srivastava, V. and M.J.M.T.P. Gupta, Approach to self-healing in metal matrix composites: a review. 2018. **5**(9): p. 19703-19713.
[29]. Blaiszik, B.J., et al., Self-healing polymers and composites. 2010. **40**: p. 179-211.
[30]. Ibrahim, M.A., et al., Mechanical properties of aluminium matrix composite including SiC/Al2O3 by powder metallurgy-a review. 2019. **7**(3): p. 23-38.
[31]. Surappa, M.K.J.S., Aluminium matrix composites: Challenges and opportunities. 2003. **28**: pp. 319-334.
[32]. Kundu, S. and S.C. Mondal. Development of Al–Cu Metal Matrix Composite Using Powder Metallurgy Technique. in Design

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 05 May 2024, pp: 396-413 www.ijaem.net ISSN: 2395-5252

for Tomorrow—Volume 3: Proceedings of ICoRD 2021. 2021. Springer.
[33]. Dyzia, M.J.M., Aluminum matrix composite (AlSi7Mg2Sr0. 03/SiCp) pistons obtained by mechanical mixing method. 2017. **11**(1): p. 42.
[34]. Rohatgi, P.K.J.D.s.j., Metal matrix composites. 1993. **43**(4): p. 323.
[35]. Mavhungu, S., et al., Aluminum matrix composites for industrial use: advances and trends. 2017. **7**: p. 178-182.
[36]. Baisane, V., et al., Recent development and challenges in the processing of ceramics reinforced Al matrix composite through stir casting process: A Review. 2015. **2**(10): p. 257814.
[37]. Tripathy, A., et al., Synthesis and Characterization of Ultra-Fine Al-Al 2 O 3 Composite by Powder Metallurgy Route.
[38]. Adebisi, A., et al., Metal matrix composite brake rotor: historical development and product life cycle analysis. 2011. **4**: p. 471-480.
[39]. Lyu, Y., et al., A friction, wear and emission tribometer study of non-asbestos organic pins sliding against alsic mm discs. 2018. **40**(2): p. 274-282.
[40]. Srivastava, V., M.J.M. Gupta, and M. International, Impact of post hardening mechanism on self-healing assessment of AA2014 nitinol-based smart composites. 2021. **27**: p. 2666-2681.
[41]. Alaneme, K.K. and M.J.A.T.C.-b.o.e. Bodunrin, Mechanical behaviour of alumina reinforced AA 6063 metal matrix composites developed by two step-stir casting process. 2013. **6**(3): p. 105.
[42]. Kanta, D.D., et al., Properties of ceramic-reinforced aluminium matrix composites—a review. 2014. **9**: p. 1-12.
[43]. Oladijo, O., et al., Investigating the self-healing behaviour of under-aged and 60Sn-40Pb alloy reinforced aluminium hybrid composites. 2016. **620**: p. 201-205.
[44]. Pozdniakov, A., et al., Microstructure and material characterization of 6063/B4C and 1545K/B4C composites produced by two stir casting techniques for nuclear applications. 2016. **664**: p. 317-320.
[45]. Annigeri, U.K., G.V.J.J.o.T. Kumar, and Evaluation, Physical, Mechanical, and Tribological Properties of Al6061-B C Composites. 2019. **47**(6): p. 4465-4477.
[46]. Mazahery, A. and M.O.J.T.T. Shabani, Existence of good bonding between coated B4C reinforcement and al matrix via semisolid techniques: enhancement of wear resistance and mechanical properties. 2013. **56**(3): p. 342-348.
[47]. Suresh, V., et al., Tribological behaviour of aluminium/boron carbide (B4C)/graphite (Gr) hybrid metal matrix composite under dry sliding motion by using ANOVA. 2016. **53**(3-4): p. 204-217.
[48]. Manikandan, R., T.J.M. Arjunan, and M. International, Microstructure and mechanical characteristics of CDA–B 4 C hybrid metal matrix composites. 2021. **27**: pp. 885-899.
[49]. Gudipudi, S., et al., A study on geometrical features of electric discharge machined channels on AA6061-4% B4C composites. 2020. **53**(3-4): p. 358-377.
[50]. Gudipudi, S., et al., Fabrication and experimental study to optimize the recast layer and the material removal in electric discharge machining (EDM) of AA6061-B4C composite. 2019. **19**: p. 448-454.
[51]. Mahesh, V., et al., Processing of surface-treated boron carbide-reinforced aluminium matrix composites by liquid–metal stir-casting technique. 2011. **45**(23): p. 2371-2378.
[52]. Abdizadeh, H., M.A.J.A.J.f.S. Baghchesara, and Engineering, Optimized Parameters for Enhanced Properties in Al–B _ 4 4 C Composite. 2018. **43**: p. 4475-4485.
[53]. Reddy, P.S., R. Kesavan, and B.J.S. Vijaya Ramnath, Investigation of mechanical properties of aluminium 6061-silicon carbide, boron carbide metal matrix composite. 2018. **10**: p. 495-502.
[54]. Raj, R. and D.J.P.o.t.I.o.M.E. Thakur, Part C: Journal of Mechanical Engineering Science, Effect of particle size and volume fraction on the strengthening mechanisms of boron carbide reinforced aluminium metal matrix composites. 2019. **233**(4): p. 1345-1356.
[55]. Kumar, V.A., et al., Tensile and compression behaviour of boron carbide reinforced 6061Al MMC's processed through conventional melt stirring. 2018. **5**(8): p. 16141-16145.
[56]. Khare, M., R.K. Gupta, and B.J.M.r.e. Bhardwaj, Dry sliding wear behaviour of Al 7075/Al2O3/B4C composites using mathematical modelling and statistical analysis. 2019. **6**(12): p. 126512.

[57]. Park, B., et al., Automated quantification of reinforcement dispersion in B4C/Al metal matrix composites. 2020. **181**: p. 107584.

[58]. Auradi, V., et al., Preparation and evaluation of mechanical properties of 6061Al–B4Cp composites produced via two-stage melt stirring. 2014. **29**(2): p. 194-200.

[59]. Ibrahim, M., et al., Metallurgical parameters controlling matrix/B4C particulate interaction in aluminium–boron carbide metal matrix composites. 2013. **26**(6): p. 364-373.

[60]. Canakci, A., F. Arslan, and I.J.J.o.M.S. Yasar, Pre-treatment process of B 4 C particles to improve incorporation into molten AA2014 alloy. 2007. **42**: p. 9536-9542.

[61]. Mishra, P., et al., Modeling of microwave heating of particulate metals. 2006. **37**: p. 839-845.

[62]. Aparna, K., et al., Role of metallic and composite (ceramic–metallic) supports on microwave heating of porous dielectrics. 2007. **50**(15-16): p. 3072-3089.

[63]. Matli, P.R., R.A. Shakoor, and A.M.A.J.S.o.F.M. Mohamed, Development of metal matrix composites using microwave sintering technique. 2018.

[64]. Menezes, R.R., P.M. Souto, and R.J.C.I. Kiminami, Microwave Fast Sintering of Ceramic Materials in Sintering of Ceramics-New Emerging Techniques. 2012: p. 610.

[65]. Luo, S., et al., Microwave heating, isothermal sintering, and mechanical properties of powder metallurgy titanium and titanium alloys. 2013. **44**: pp. 1842-1851.

[66]. Sun, J., W. Wang, and Q.J.M. Yue, Review on microwave-matter interaction fundamentals and efficient microwave-associated heating strategies. 2016. **9**(4): p. 231.

[67]. Motshekga, S.C., et al., Recent trends in the microwave-assisted synthesis of metal oxide nanoparticles supported on carbon nanotubes and their applications. 2012. **2012**: p. 51-51.

[68]. Venkatesh, M. and G.J.B.e. Raghavan, An overview of microwave processing and dielectric properties of agri-food materials. 2004. **88**(1): p. 1-18.

[69]. Karayannis, V.G. Microwave sintering of ceramic materials. in IOP Conference Series: Materials Science and Engineering. 2016. IOP Publishing.

[70]. Britnell, D. and K.J.J.o.m.p.t. Neailey, Macrosegregation in thin walled castings produced via the direct squeeze casting process. 2003. **138**(1-3): p. 306-310.

[71]. Manjunath Patel, G., P. Krishna, and M.J.A.i.A.E. Parappagoudar Modelling in squeeze casting process-present state and future perspectives. 2015. **4**(1): p. 1-9.

[72]. Lupulescu, A., et al. Science of Casting and Solidification: ASM Handbook Contributions—Honoring Professor Doru Michael Stefanescu. in Advances in the Science and Engineering of Casting Solidification: An MPMD Symposium Honoring Doru Michael Stefanescu. 2016. Springer.

[73]. Bhandare, R.G., P.M.J.I.J.o.E. Sonawane, and A. Technology, Preparation of aluminium matrix composite by using stir casting method. 2013. **3**(3): p. 61-65.

[74]. Jokhio, M.H., M.I. Panhwer, and M.A.J.a.p.a. Unar, Manufacturing of aluminium composite material using a stir casting process. 2016.

[75]. Vijaya, D.J., J.P. Kumar, and D.R.J.M.T.P. Smart, Analysis of hybrid aluminium composite material reinforced with Ti and NbC nanoparticles processed through stir casting. 2022. **51**: p. 561-570.

[76]. Smart, D.R., J.P. Kumar, and R.S.J.M.T.P. Cyrus, Development and investigations of Al5083/CNT/Ni/MoS2 metal matrix composite for offshore applications. 2019. **19**: pp. 682-685.

[77]. Hanizam, H., et al., Optimisation of mechanical stir casting parameters for fabrication of carbon nanotubes–aluminium alloy composite through Taguchi method. 2019. **8**(2): p. 2223-2231.

[78]. Zhu, J., et al., Microstructure and mechanical properties of SiCnp/Al6082 aluminium matrix composites prepared by squeeze casting combined with stir casting. 2020. **283**: p. 116699.

[79]. Zhang, M., et al., Effect of pressure on microstructures and mechanical properties of Al-Cu-based alloy prepared by squeeze casting. 2007. **17**(3): p. 496-501.

[80]. Gudipudi, S., et al., Enhanced mechanical properties of AA6061-B4C composites

developed by a novel ultra-sonic assisted stir casting. 2020. **23**(5): p. 1233-1243.
[81]. Nestler, D., et al. Powder metallurgy of particle-reinforced aluminium matrix composites (AMC) using high-energy ball milling. in Integrated Systems, Design and Technology 2010: Knowledge Transfer in New Technologies. 2011. Springer.
[82]. Cheng, N., S. Zeng, and Z.J.J.o.m.p.t. Liu, Preparation, microstructures and deformation behaviour of SiCP/6066Al composites produced by PM route. 2008. **202**(1-3): p. 27-40.
[83]. Beffort, O., et al., Alloying effects on microstructure and mechanical properties of high volume fraction SiC-particle reinforced Al-MMCs made by squeeze casting infiltration. 2007. **67**(3-4): p. 737-745.
[84]. Ozdemir, I., et al., Microstructure characterization of Al-Al2O3p composites produced by high energy ball milling. 2007. **44**(3).
[85]. Ozdemir, I., et al., Nanocrystalline Al–Al2O3p and SiCp composites produced by high-energy ball milling. 2008. **205**(1-3): p. 111-118.
[86]. Özdemir, I., et al., The production of ultra-fine grained Al-SiCp composites produced via high energy ball milling. 2008. **45**(3): p. 136-149.
[87]. Shorowordi, K.M., et al., Microstructure and interface characteristics of B4C, SiC and Al2O3 reinforced Al matrix composites: a comparative study. 2003. **142**(3): p. 738-743.
[88]. Suryanarayana, C.J.P.i.m.s., Mechanical alloying and milling. 2001. **46**(1-2): p. 1-184.
[89]. Maneshian, M., et al., Structural changes during synthesizing of nanostructured W–20 wt% Cu composite powder by mechanical alloying. 2007. **445**: p. 86-93.
[90]. Tjong, S.C.J.A.e.m., Novel nanoparticle-reinforced metal matrix composites with enhanced mechanical properties. 2007. **9**(8): p. 639-652.
[91]. Angelo, P., R. Subramanian, and B. Ravisankar, Powder metallurgy: science, technology and applications. 2022: PHI Learning Pvt. Ltd.
[92]. Ravichandran, M., A.N. Sait, and V.J.M.R. Anandakrishnan, Workability studies on Al+ 2.5% TiO2+ Gr powder metallurgy composites during cold upsetting. 2014. **17**: p. 1489-1496.
[93]. Tsutsui, T.J.H.C.T.R., Recent technology of powder metallurgy and applications. 2012. **54**: p. 12-20.
[94]. Bermudez, M., et al., Dry and lubricated wear resistance of mechanically-alloyed aluminium-base sintered composites. 2001. **248**(1-2): p. 178-186.
[95]. Miyajima, T. and Y.J.W. Iwai, Effects of reinforcements on sliding wear behaviour of aluminium matrix composites. 2003. **255**(1-6): p. 606-616.
[96]. Schmidt, A., et al., Particle-reinforced aluminium matrix composites (AMCs)—Selected results of integrated technology, user, and market analysis and forecast. 2018. **8**(2): p. 143.
[97]. Mohapatra, S.K., K.J.I.J.o.M. Maity, and M. Engineering, Synthesis and characterisation of hot extruded aluminium-based MMC developed by powder metallurgy route. 2017. **12**: p. 1-9.
[98]. Purohit, R., et al., Fabrication of Al-SiCp composites through powder metallurgy process and testing of properties. 2012. **2**(3): p. 420-437.
[99]. Erdemir, F., A. Canakci, and T.J.T.o.N.M.S.o.C. Varol, Microstructural characterization and mechanical properties of functionally graded Al2024/SiC composites prepared by powder metallurgy techniques. 2015. **25**(11): p. 3569-3577.
[100]. Shaikh, M.B.N., S. Arif, and M.A.J.M.R.E. Siddiqui, Fabrication and characterization of aluminium hybrid composites reinforced with fly ash and silicon carbide through powder metallurgy. 2018. **5**(4): p. 046506.
[101]. Nuruzzaman, D.M., et al., Effect of sintering temperature on the properties of aluminium-aluminium oxide composite materials. 2016. **1**(2): p. 59-64.
[102]. Rahimian, M., et al., The effect of sintering temperature and the amount of reinforcement on the properties of Al–Al2O3 composite. 2009. **30**(8): p. 3333-3337.