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Mechanical Characterization of Aluminium Alloy /Alumina Nano Composites Under Controlled Solidification employing Chills

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Abstract:- A composite material is formed by combining two or more chemically distinct and insoluble phases, showcasing properties and structural capabilities that surpass those of the individual components when acting independently. In the field of engineering, aluminum alloy holds considerable significance and is extensively utilized in the aircraft and aerospace industry for the fabrication of various parts and components. Its appeal as a metal matrix composite lies in its impressive strength-to-density ratio. This research centers on the mechanical characterization of aluminum alloy (Al2024) / alumina nano composites (Al_2O_3) achieved through controlled solidification using chills. The creation of the Aluminum (Al2024) alloy / Alumina Nano-Composite was conducted, influenced by both ferrous and nonferrous end chills. Mechanical tests revealed improved ultimate tensile strength up to 150 N/mm^2 for copper chill of 9 wt% nano alumina reinforcement and also observed the composite with 9 wt% nano alumina reinforcement, cast with a copper chill, has the highest Vikers hardness value of 116, showcasing superior performance compared to other utilized chills.

Keywords*:* Nano Alumina, End Chills, Stir Casting, Controlled Solidification

1. Introduction

Aluminum alloys stand out as the most extensively employed matrix materials in Metal Matrix Composites (MMCs), both in industrial applications and research. This preference is attributed to the low density of aluminum alloys, robust corrosion resistance, and cost-effectiveness compared to other low-density alloys like Mg or Ti [2]. Furthermore, aluminum alloys boast outstanding mechanical and technological properties, including a high strength-to-wear ratio, castability, weldability, and machinability. Within the spectrum of aluminum alloys, Alloy 2024 emerges as a prominent choice, featuring copper as its primary alloying element. Alloy 2024 maintains impressive strength characteristics and high corrosion resistance [4]. Its notable strength and fatigue resistance make it widely employed in aircraft applications, particularly in wing and fuselage structures under tension and in aircraft fittings [6]. Aluminum alloy 2024 is utilized in two primary forms: plate and sheet. Plate forms demand properties like stiffness and good fatigue strength for use in wing tension members, fuselage structures, ribs, shear webs and other structural areas of aircraft. Conversely, sheet forms find application in both commercial and military aircraft for fuselage skins [5].

Suitable Method to Fabricate Metal Matrix Composite

Upon reviewing various research papers and articles, it became evident that several techniques exist for the production of aluminum matrix composites, ranging from powder metallurgy to casting methods [9]. A key objective of this review article is to identify the most efficient fabrication method for fabricating a composite of aluminum alloy 2024, emphasizing a cost-effective and straight forward production approach [11]. The enhanced stirring action in stir casting processes contributes to improved bonding strength between the reinforced particles and the matrix [15].

Current Status of Research

Numerous researchers and their colleagues have conducted extensive studies on metal matrix composites, particularly focusing on Aluminum matrix composites with diverse reinforcements and various fabrication methods. For instance, Abdo HS et al. [1] explored the mechanical characterization of Aluminum alloy 2024 reinforced with beryl. The study revealed a notable improvement in ultimate tensile strength by 107%, hardness by approximately 11%, and a remarkable increase in toughness by almost 300%. This indicates a significant enhancement in the properties of Al 2024-beryl composites compared to Al2024 As-cast material. Another investigation by Sun S, Fang Y [3] involved the development of Aluminum alloy 2024-based metal matrix composites with yttrium reinforcement using the sand casting method. The study found that the optimum properties were achieved at 0.3 wt% yttrium reinforcement, but an increase beyond this concentration led to a gradual decrease in properties. Mechanical properties like yield strength (YS), hardness and ultimate tensile strength (UTS) were determined to be 114 HV, 388, and 343 MPa, respectively. Additionally, Anijdan SM et al. [5] conducted a research on the synthesis of Aluminum-silicon agro-waste-based hybrid metal matrix composites. The study involved reinforcing Al 2024 with nano alumina (Al_2O_3) to enhance mechanical properties. The results indicated enhanced tensile strength and hardness, especially with copper chills, showcasing superior performance compared to other utilized chills**.**

Relevance of the Present Research

A metallic insert in the mould known as a chill is the key to achieving efficient mechanical characterization in sand casting (12). It is difficult to achieve strong directional solidification in the casting of complex aluminium alloy objects without the use of chilling. In order to accomplish adequate directional solidification, chills must be used frequently because the metal has a tendency to commence solidification throughout, making correct feeding difficult (18). In metal casting, chills—metallic inserts incorporated into the sand surface allow for a high solidification rate. Generally, the cooling rate of the metal in the mould is determined by the casting's thickness [25]. When the design of the moulding cavity inhibits natural directed solidification, adding a cold in the right place might encourage it and result in better mechanical qualities. Chills come in two varieties: internal and exterior. Chills can be machined or cast, and are typically made of iron, aluminium, or copper [21]. The desired thermal effects and simplicity of production are the deciding factors for selecting a cold. The size, conductivity, thermal capacity, and heat transfer across the molten metal alloy/chill contact all affect how effective the chill is. It can, nevertheless, have a significant effect on microstructure and mechanical characterization (28). The sole objective of this study is to assess how various materials function as chills in sand casting with the goal of accelerating solidification rates and improving mechanical and Microstructural characteristics [27].

2. Methods

Materials: In this research work we used the Aluminium Alloy 2024, Alumina nano powder (Al2O3) to prepare the composite material. The Aluminum being available in various alloys namely Al-1000 series to Al-7000 series; the Aluminum chosen for the following study was Al2O3. The Aluminum was procured from FENFE METALLURGICALS SUPPLIERS BENGALURU. The procured pure Aluminum properties can be seen in the table.

Table No 1: Aluminum Al2024 Mechanical Properties

Alloy	Ultimate Tensile strength (MPa)	Tensile Yield Strength (MPa)	Fatigue Strength (MPa)	Shear Strength (MPa)	Modulus of Elasticity (GPa)	Shear Modulus (GPa)	Hardness
							HB
Al2024	185	75	90	125	73.1	28	47

The Alumina nano particles (Al_2O_3) were procured from Adnano Technologies Private Limited, Shimoga. The important description of the procured Alumina (Al_2O_3) nano particles can be seen in table.

Table No 2: Alumina nanoparticles (Al_2O_3) Characterization

Sl. No	Al_2O_3	Description
1	Purity	99.9%
2	Average Particle Size	30-50 nm
3	Molecular Weight	101.96g/mol
4	Melting point	2055ºC
5	Bulk Density	02-0.4g/cm3
6	Physical Form	Powder
7	Morphology	Near Spherical

Method of Manufacturing: In this project we have used the stir casting process to develop Alumina nano composites.

Stir Casting Process

A limitation of conventional casting methods lies in the insufficient distribution of reinforcing phases throughout the liquid composite matrix. In response to this challenge, stir casting is employed as a remedy. This technique involves essential physical stirring or blending within the furnace, aiming to produce components that undergo extrusion for the elimination of porosity, refinement of microstructure, and the uniform distribution of reinforcement. The stir casting process for alloy composites specifically focuses on preventing the separation of reinforcing materials due to surfacing or settling during the melting and casting of composite specimens. The distribution of particles in the molten matrix composite is influenced by a number of factors, including the crucible temperature, the size and form of the reinforcing particles, the mechanical stirrer, stirring settings, and placement in the molten liquid. Notably, stir casting stands out as one of the most cost-effective methods among the recognized manufacturing approaches for metal matrix composites (MMCs).

Figure 1: Stir casting setup

(a) **(b)**

Figure 2: a) Chills arrangement b) Tensile test specimen

Solidification Process in Aluminium Alloys

To mitigate the effects of shrinking-induced faults, a solidification process is essential. The initiation of the solidification process occurs as soon as the molten metal is introduced into a sand mold. Cohesiveness and structural properties develop in the cast form during this solidification phase. The mode of solidification significantly influences the qualities of the casting, giving rise to a metallographic structure during this process. In terms of properties, pure metals surpass alloys in thermal and electrical conductivity, ductility, melting point, yield point, tensile strength, and corrosion resistance. However, casting pure metals poses challenges due to their high melting temperatures. In the manufacturing of aerospace and commercial castings, metallic chills are commonly employed to control solidification and reduce shrinkage porosity. Various chill materials, including copper, brass, mild steel, cast iron and graphite, have been utilized for this purpose.

Chills: A chill, in the context of casting, refers to any object employed to reduce the temperature of the casting at its specific location. This is achieved through a combination of high specific heat and strong heat conductivity. In the manufacturing of aerospace and commercial castings, metallic chills are frequently employed to regulate solidification and mitigate shrinkage porosity. In the current study, a range of chill materials has been utilized, including copper, brass, mild steel, cast iron and graphite

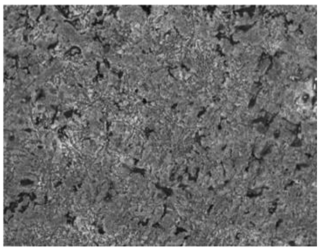
3. Methodology

In this research, the sample preparation involves the implementation of the stir casting technique. Initially, Aluminum alloy (Al2024) is placed in a graphite crucible and melted in an electric furnace, attaining a temperature of 700˚C. Concurrently, Alumina Nano powder (Al_2O_3) is preheated to approximately 200˚C. The preheated Alumina Nano powder is then introduced into the molten alloy and thoroughly stirred for approximately 12 minutes using an electric stirrer. The resulting Metal Matrix Composites (MMCs) are created by varying the weight percentage of the reinforcement, ranging from 3 wt. %, 6 wt. %, 9 wt. %, to 12 wt. %.

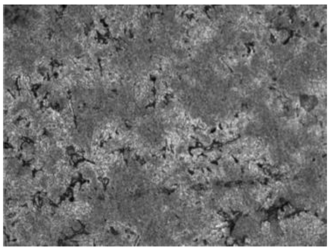
Chilling Effect: The utilization of chills has demonstrated remarkable effectiveness in crafting high-quality castings. Studies show that when strategically positioned in the mold cavity, chills contribute to improved and controlled solidification, ultimately minimizing the occurrence of casting defects such as voids and hot tears. When aluminum and its alloys serve as matrix materials, the use of either external or internal chilling is typically essential. In this study, an endeavor was made to incorporate end chills with diverse volumetric heat capacities strategically positioned within the mold cavity.

4. Results and Discussions

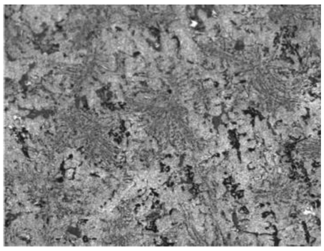
Microstructural parameters play a crucial role in determining the mechanical properties of composites. The evolution of microstructure is influenced by various process parameters, with cooling conditions during solidification being particularly significant in determining the final material structure. In this current investigation, Figure 3 displays optical micrographs of Aluminum 2024 with 9 wt. % nano alumina (Al_2O_3) reinforcement for copper, brass, mild steel, cast iron and graphite chills. Among these combinations, Aluminum 2024 with 9 wt. % nano alumina (Al_2O_3) reinforcement for Copper demonstrates the highest values for tensile strength and hardness.



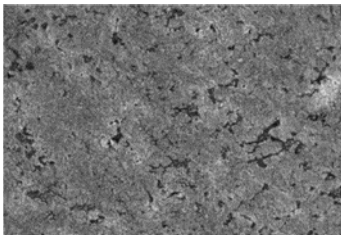
a. Copper chill



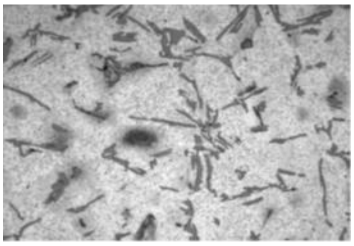
b. Mild steel chill



c. Cast iron chill

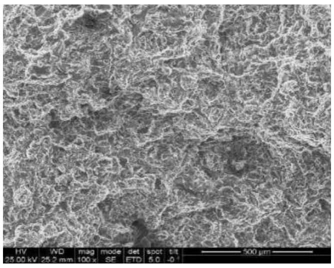


d. Brass chill

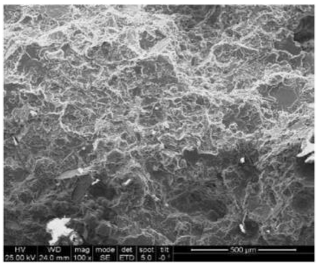


e. Graphite chill

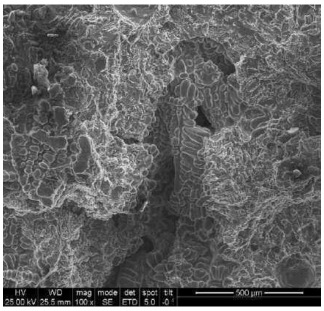
Figure 3: (a) to (e) Microstructure of Aluminium 2024 with 9 wt. % nano alumina (Al_2O_3) reinforcement effect on different chills.



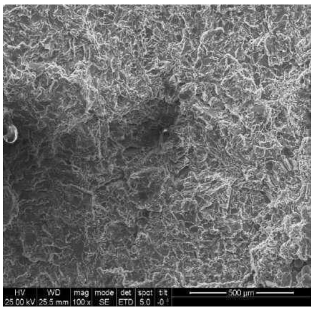
(a)



(b)



(c)



(d)

Figure 4: (a) to (d) SEM Fractography of Cu chilled MMC with a) 3 wt. % b) 6 wt. % c) 9 wt. % and d) 12 wt. % reinforcement(100X)

Mechanical Properties

Ultimate Tensile Strength (UTS) of the Chilled Composite

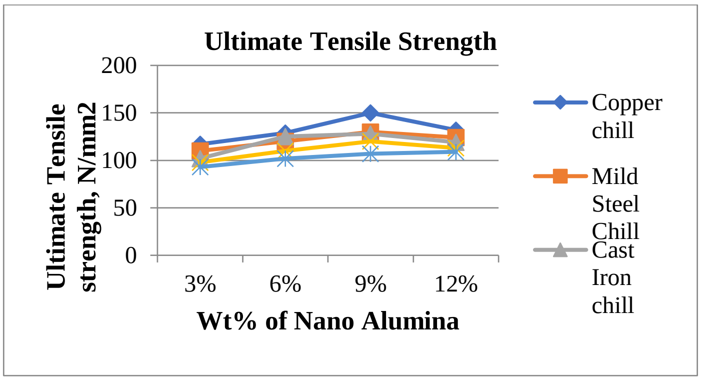


Figure 5: wt. % reinforcement Vs UTS for MMCs using different chill

In recent decades, there has been a significant embrace of metal matrix composites as structural materials, primarily due to their enhanced strength and outstanding strength-to-weight ratio. The effectiveness of these composites is attributed to their ability to effectively transfer applied loads to tougher reinforcements via a pliable and ductile matrix metal. To achieve this goal, ongoing research has incorporated crucial chilling processes, with the aim of establishing a resilient interfacial bonding between the diverse phases that form the composite.

Figure 5 illustrates how the amount of reinforcement in different Metal Matrix Composites (MMCs) made using different kinds of metals affects the composites' ultimate tensile strength (UTS). Interestingly, the UTS reach its minimum with the graphite chill and reach its maximum in the composite chilled with copper. In addition, a review of the microstructure and results of strength tests indicates that an increase in reinforcement content increases UTS to a maximum of 9 weight percent, beyond which it decreases as a result of uneven reinforcement distribution and cluster formation. At certain locations, these clusters serve as stress concentrators, preventing load transfer and reducing strength. There are multiple cases where MMCs reinforced with ceramics outperform the unreinforced matrix alloy in terms of mechanical properties. These differences can be attributed to greater dislocation densities caused by variations in the coefficient of thermal expansion.

Nevertheless, ongoing research reveals a noteworthy increase in the Ultimate Tensile Strength (UTS) attained for aluminum 2024 when reinforced with nano alumina. This observed enhancement in UTS underscores the significant influence of nano alumina reinforcement and chilling on mechanical strength. Prior investigations have underscored the dependence of composite strength on variables such as the type of reinforcement, the quality of the interfacial bond between the reinforcement and matrix, particle distribution, and particle size. In the present study, beyond considering conventional parameters, the attainment of robust casting with a refined grain structure, facilitated by chilling and preheating of the reinforcement, proves to be crucial in further augmenting Ultimate Tensile Strength (UTS). The outcomes from the mechanical characterization of aluminum 2024 reinforced with nano alumina Metal Matrix Composites (MMCs) indicate that strength is intricately linked to both reinforcement content and the chilling effect.

Hardness test

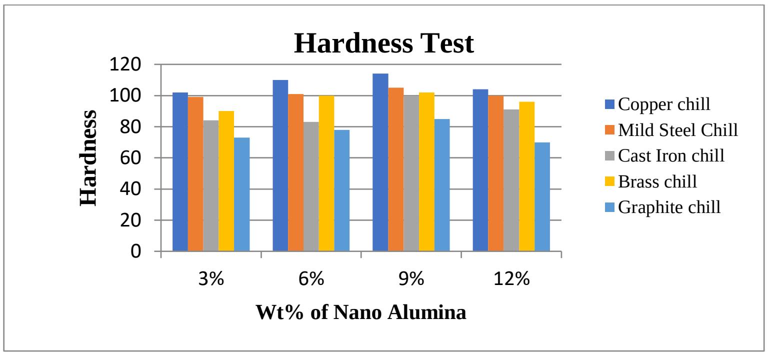


Figure 6: wt. % reinforcement Vs Hardness for different MMCs

Using different chills

The hardness test findings show a favorable correlation between the increase in weight percentages of reinforcement and hardness. The strong link between the Nano Al_2O_3 particles and the matrix, as well as their high hardness values, is the reasons for this correlation. Because the reinforcement particles are stronger than the embedding matrix, they prevent dislocation movement. The graphical depiction shows that the composite with 9 wt% reinforcement, cast with a copper chill, has the highest hardness values. But after this point, the hardness of the alloy decreases due to a higher concentration of the brittle and hard Nano Al_2O_3 phase. The higher hardness value is partly a result of the higher dislocation density. Furthermore, the outcomes of the hardness measurement show that the type of chill used affects composite hardness, with a copper chill producing the highest level of hardness and a graphite chill producing the lowest.

5. Conclusion

The conducted research leads to the conclusion that employing various chills, such as Cast iron, Copper, Mild steel, Brass, and Graphite, in the tensile and hardness tests of the Aluminum 2024/Alumina nano composite yields improved results. The outcomes from both the tensile and hardness tests highlight the superior properties exhibited by copper end chills in comparison to all other chills, particularly notable for the 9 wt. % reinforcement of Nano Al2O3 Metal Matrix Composite (MMC).

Using chilling techniques and Nano Al2O3 reinforcement in an Aluminium 2024 matrix, the main goal of this research is to produce Metal Matrix Composites (MMCs) of exceptional quality and structural integrity. Important insights are gained from the mechanical and Microstructural examination of the resulting chilled composite. Microstructural analyses demonstrate a finely grain-structured, well-bonded reinforcement that is ascribed to the chilling process. The strong bonding between the matrix and reinforcement made possible by chilling, the efficient integration of Nano Al2O3 reinforcement, and the fine grain structure all have a major impact on the chilled MMCs' Ultimate Tensile Strength (UTS). Remarkably, both hardness and strength show increases up to 9 Wt% reinforcement, suggesting that reinforcement over this threshold has minimal impact on the mechanical characteristics of the MMCs.

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