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Effect of Dct Copper Chill Plate on Al6061 Alloys Incorporated into Silicon Carbide Composites Via Stir Die Casting Process: An Experimental Study

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Abstract: - Aluminum-Silicon Carbide Metal Matrix Composites (Al/SiC) are materials that are formed by combining aluminum with silicon carbide particles as the reinforcement material. Al/SiC offer several advantages over traditional aluminum alloys, making them an attractive material for various applications.The research was conducted to fabricate the composite comprising of aluminum as the matrix and SiC particles as the reinforcement (size 40-50µm). The reinforcement being supplemented varies starting from 3 to 12 wt. % in stepladders of 3 wt. %. The development of composite was cast in sand mould patterns comprising chill blocks (DCT Copper and regular copper) remained verified for their material properties.It was observed that the maximum tensile strength for Al/SiC composites was obtained for specimens cast with a DCT copper chill, while it was minimal for Cu-chill. The increase in thermal conductivity of the chill plate leads to an increase in strength, whereas an increase in composite hardness results in higher tensile strength due to the finer grain structure obtained during the solidification process at a higher cooling rate.Furthermore, The micro-structure pictures clearly show that specimens cast with DCT-copper chill plates show small grains, while specimens cast with CU chill show coarse grains. It is further confirmed by comparing the micro-structures on the Cu chill side that the DCT-copper chill yields much finer grain sizes than the CU chill, which produces coarser grains.

Keywords: Aluminum-Silicon Carbide ,DCT Copper Plate,Higher Cooling Rate,Thermal Conductivity;

1. INTRODUCTION

Composites made of aluminium have several industrial uses, including in the aerospace, space, automotive, and structural industries [1]. Although composites are commonly used materials,

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there are several secondary forming process restrictions that make it difficult to expand the range of nine applications for composites made of aluminium. This restriction is mostly caused by the composites' an isotropic makeup. Due to their superior combination of physical, mechanical, and tribological qualities over base alloys, Al-alloy matrix composites (AMCs) incorporating hard dispersion are becoming increasingly important in industry [2].

As a result, in addition to the weight savings, these composites are used in a number of automotive and technical components where wear, tear, and seizure are key issues. The process of powder metallurgy has significant drawbacks. The fact that the fabrication process is relatively complicated, and the material handling procedures are heavy is one of this strategy's key drawbacks [3]. As a result, the output is more expensive than wrought goods made using traditional casting methods. It is possible that less interracial contact will occur between the reinforcing particles and the matrix because the brittle ceramic particles are fracture during powder blending. There are other places where you may read in-depth discussions on the many producers involved in making powder metallurgy MMCs [4]. The concept of cryogenic treatment is rooted in metallurgical principles related to phase transformations and micro structural changes that occur in metals when subjected to low temperatures. At cryogenic temperatures, the mobility of atoms within the metal lattice decreases significantly, allowing for the rearrangement of atomic structures and the stabilization of certain phases [5]. This results in the refinement of the micro structure, reduction of residual stresses, and enhancement of mechanical properties. The vortex technique or stir-casting technique is the most basic and widely utilized method. The vortex approach involves introducing pre-treated ceramic particles into the revolving impeller's molten 12 alloy vortex. A number of aluminium businesses improved and altered the procedure, which is now used to produce a number of AMCS on a large scale. Particularly during the melt and afterwards during solidification, micro-structure in-homogeneities can lead to particle agglomeration and sedimentation [6]. As a result of interactions between moving solid- liquid interface and suspended ceramic particles during solidification, in-homogeneity in reinforcement distribution in these cast composites could also be an issue. Typically, a variety of molten aluminium alloys can contain up to 30% ceramic particles with a size range of 5 to 100micrometers. It is possible to transfer the melt-ceramic particle slurry directly into a shaped mould before it has fully solidified, or it is possible to let it solidify into billets or rods so that it can be reheated to the slurry form for further processing using techniques like die casting and investment casting. Sub-micron ceramic particles or whiskers cannot be included into the process. Compo-casting is an additional stir casting method variation. In this instance, semi- solid ceramic particles are included into the alloy [7].

2. LITERATURE REVIEW

The stir casting method to make MMC with Aluminium 2024 as a matrix and beryl particles as reinforcement, swirling at 350 rpm for 8 minutes. The composites were made by altering the percentage of Beryl in the matrix, and the particles were distributed uniformly throughout the matrix. They investigated the tribological properties of MMCs. Al-alloy is combined with reinforcements such as alumina and graphite. Stir casting is an easier and more cost-effective liquid processing technology for fabricating particle, discontinuous fibre reinforced

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composites, according to them. Mg is used as a wetting agent to improve inter-facial bonding between matrix materials and hard reinforced particles. The investigated the performance of stir cast Al2O3 and SiC reinforced Al metal matrix composites. The results demonstrated that the composite materials have improved physical and mechanical properties such as high hardness, high effect, and 23.68 percent ultimate tensile strength. The composite materials in automotive parts can be applied as possible lightweight materials. It has been observed experimentally that the Aluminum composites with Al2O3 exhibited a lower wear rate than composites with SiC reinforcement particles. The majority of MMC research focuses on the matrix phase of aluminium alloy. The combination of ductility, lightweight, corrosion resistance, environmental strength, and useful mechanical properties looks promising. As a lightweight material, aluminium has a density of 2.7 g/cm3 and a melting point of 660.3 °C. Aluminum 6061 is a widely used aerospace and transportation alloy known for its strength, corrosion resistance, and durability. The aluminum-silicon-magnesium alloy is considered one of the most versatile aluminum alloys available and is used in a variety of applications. In addition to its strength and corrosion resistance, 6061 aluminum is also known for its durability. It is a highly stable and long-lasting material that can withstand high levels of stress and strain over time [8]. Silicon carbide is a ceramic material that has been used in various applications due to its exceptional properties such as high hardness, high strength, and high thermal stability. In recent years, silicon carbide has been used as a reinforcement material in aluminum matrix composites (AMCs) to enhance their mechanical properties. In addition to improving hardness and wear resistance, silicon carbide also helps to improve the strength and stiffness of AMCs. This results in increased resistance to impact and fatigue, making the composite ideal for use in high-stress applications such as aircraft and space structures [9]. The chilling layer acts as a reinforcement in the aluminum matrix, increasing the strength of the composite. This increased strength makes Al-MMCs ideal for use in high-stress applications, such as in the aerospace and automotive industries. In addition to their improved thermal conductivity and strength, Al-MMCs also have good wear resistance. The chilling layer in the composite increases the hardness of the material, making it more resistant to wear and abrasion.One of the challenges in the manufacturing of Al-MMCs is the need for precise control over the thickness of the chilling layer. The thickness of the chilling layer has a significant impact on the properties of the composite, and it is important to maintain a consistent thickness throughout the material to ensure uniform properties [10]. This review focuses on the use of cryogenic and regular copper plates as chilling materials in sand mold casting of Al-SiC composites and the subsequent evaluation of their mechanical, micro-structure, and machinability behaviors. The casting process involves pouring molten metal into a mold where it solidifies into a desired shape. Sand molds are commonly used due to their cost-effectiveness and flexibility [11]. The cooling rate during solidification is critical as it affects the grain structure, distribution of reinforcement particles, and the formation of any defects. The comparative effects of cryogenic versus regular copper plates on the cooling rate and subsequent properties of Al-SiC composites have been extensively studied. Faster cooling rates achieved with cryogenic plates not only refine the

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grain structure but also enhance the mechanical properties and machinability of the composites. Surface finish is critical for many applications requiring high precision and aesthetic quality. The smoother surface finish achieved with composites cast using cryogenic copper plates is a result of the finer grain structure and reduced tool wear [12]. Studies have reported carbide tools experiencing abrasion wear while machining AMMCs reinforced with Al2O3 particulates and A359 Al matrix composite reinforced with 20 vol.% SiC particulates. The rubbing action of the cutting tool is in the same direction as the chip flow. Coated tungsten carbide tools are more durable than conventional HSS and un coated cutting tools [13]. The presence of hard particles in aluminum matrix composites with 14 vol.% SiC particulates has been found to cause extreme flank wear of the cutting tool.

2.1 Limitations and goals

A review of a host of relevant literature on the composites leads to some important observations on the gap that prevails for developing the composite with increased strength to weight ratio, improved mechanical properties and reduced wear rate with the addition of SiC dispersion for the Al based alloy. The process of uniting different materials together opens up the opportunity to various researchers to develop new kind of materials that suits for several applications [14]. The research was conducted to fabricate the composite comprising of Al as the matrix and SiC particles as the reinforcement (size 40-50 μm). The reinforcement being supplemented varies starting from 3 to 12 wt.% in step-ladders of 3 wt.%. The resultant composite was cast in sand mould patterns comprising chill blocks (DCT Copper and regular copper) remained verified for their material properties [15].

- To investigate the sand-portrayed Al6061-SiC composites via Deep-Cryo treatment copper chills.
- To prepare the mold boxes with DCT chills and without DCT chills for to produce the Al-SiC composites.
- To prepare sand sand-portrayed Al6061-SiC composites for different percentage of SiC by using stir casting process.
- To understand the behaviour of mechanical and metallographic study as per the ASTM standards.

3.MATERIALS & PROCEDURE

The properties of aluminium that make this metal and its alloys the most economical and attractive for a wide variety of uses are appearance, light weight, excellent fabrication, good physical properties, better mechanical properties, and good corrosion resistance

3.1 Al6061 alloys matrix

However, pure aluminium and certain aluminium alloys are noted for extremely low strength and hardness. Aluminium has a density of only 2.7g/cm^3 , approximately one-third as much as steel (7.83g/cm^3), copper (8.93g/cm^3), or brass (8.53g/cm^3).It exhibits excellent corrosion

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resistance in most environments including atmosphere, water (including salt water), petrochemicals and many other chemical systems [16]. Aluminium surfaces can be highly reflective,and higher bonding. Fig.1 provides the pattern of matrix,reinforcement,and variation of compositions. Radiant energy, visible light, radiant heat, and electromagnetic waves are efficiently reflected, while anodized and dark anodized surfaces can be reflective or absorbent. The reflectance of polished aluminium, over a broad range of wave lengths, leads to its selection for a variety of decorative and functional uses. One of the most frequently used aluminium alloys is type 6061 aluminium. Numerous general-purpose applications are suitable for it due to its weld-ability and formability.Type 6061 alloy is particularly helpful in architectural, structural, and automotive applications because to its high strength and resistance to corrosion [17-20]. The Al-alloy was procured from PMC corporation, Bangalore in the form of rectangular slabs as shown in the Fig.2

Table 1: Chemical composition of copper chill plate

Elements	Cu	Zn	Sn	Pb	Fe	Si
%	96.5	3.6	0.02	0,03	0.17	0.25

3.2 Silicon carbide as reinforcement

Silicon carbide (SiC) is a ceramic material that is widely used as a reinforcement in Metal Matrix Composites (MMCs). They are advanced materials composed of a metal matrix reinforced with one or more secondary phases, typically ceramics or fibers. SiC offers several advantageous properties that make it a popular choice for reinforcement in MMCs: When incorporated into an MMC, SiC particles or fibers contribute to improved tensile strength, compression strength, and wear resistance. 40 Excellent Thermal Stability: SiC exhibits high thermal stability and can withstand elevated temperatures without significant degradation [21-22].

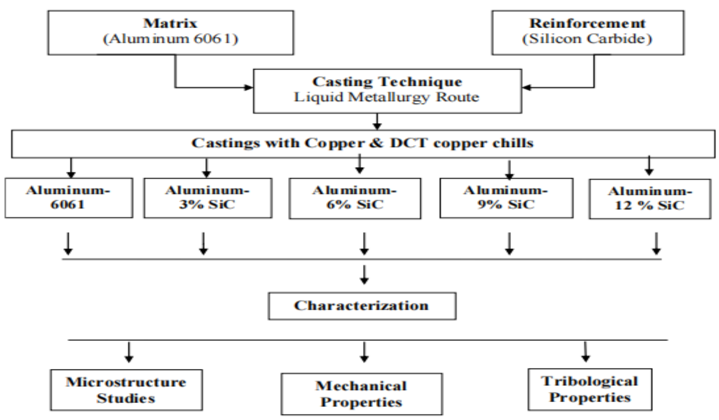

Figure 1: Pattern of matrix, reinforcement, and variation of composite compositions

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This property makes SiC reinforced MMCs suitable for applications requiring thermal resistance, such as aerospace components, automotive parts, and high-temperature machinery [23]. Low Density: Despite its high strength and hardness, SiC has a relatively low density compared to metals, resulting in lightweight MMCs with high specific strength and stiffness.

Figure 2: Schematic block of Al6061alloys

Figure 3: Silicon carbide particles of 40µm

This combination of properties makes SiC-reinforced MMCs attractive for applications where weight reduction is critical, such as in aerospace and automotive industries. Chemical Inertness: SiC is chemically inert and resistant to corrosion, oxidation, and chemical attack, even in harsh environments. This property enhances the durability and longevity of MMCs reinforced with SiC, making them suitable for corrosive and aggressive operating conditions [24].

3.3 Copper chill plate

External chills are used for the purpose of controlling rate of solidification. External chills need not be of the same material as that of the casting since fusion must not occur. In the present study copper chill with Deep Cryogenic Treatment (DCT) of temperature -196^{0}C and regular copper chill plates were used by considering their varied thermal conductivities. The Chemical composition of copper chill materials has been tested at Geological and Metallurgical Laboratories; Bangalore as shown in Table 1. At Cryoteknics and Systems in Hosur, Bangalore, the Deep Cryo-treatment was conducted on copper chill using liquid nitrogen gas. The process lasted for 48 hours, during which the temperature was maintained at -196°C [25-27]. The chill plates used in the casting process. Excellent Thermal Stability: SiC exhibits high thermal stability and can withstand elevated temperatures without significant degradation. This property makes SiC-reinforced MMCs suitable for applications requiring thermal resistance, such as aerospace components, automotive parts, and high-temperature machinery. Low Density: Despite its high strength and hardness, SiC has a relatively low density compared to metals, resulting in lightweight MMCs with high specific strength and stiffness.This combination of properties makes SiC-reinforced MMCs attractive for applications where

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weight reduction is critical, such as in aerospace and automotive industries. Fig.3 shows that silicon particle size of 40-50µm

3.4 Stir die-casting process

Simple sand mold is prepared for casting by placing chill plates at the four side and the remaining two sides by Casting green sand process. Lower thermal conductivity and higher thickness of the insulating sand makes the sand side boundary as adiabatic and high conductivity of the Chill plates permit the heat extraction only through the plates. To prevent any leakage of the molten metal from the joints, the edges were sealed with DYCOTE 140 ceramic paste [28]. A spruce and a riser were made on cope side of the mold box. The final dimension of the cavity 200mm x 200mm x 25mm. Fig.4 shows the stir die-casting process representing the arrangement of mold. The experiment utilized commercially available Aluminium 6061 and silicon Carbide with a size of 105 microns as the base metal and reinforcement, respectively. To melt the Aluminum, an electrical resistance furnace was used. Once the matrix was melted, a stirrer was employed to create a fine vortex, ensuring proper mixing.

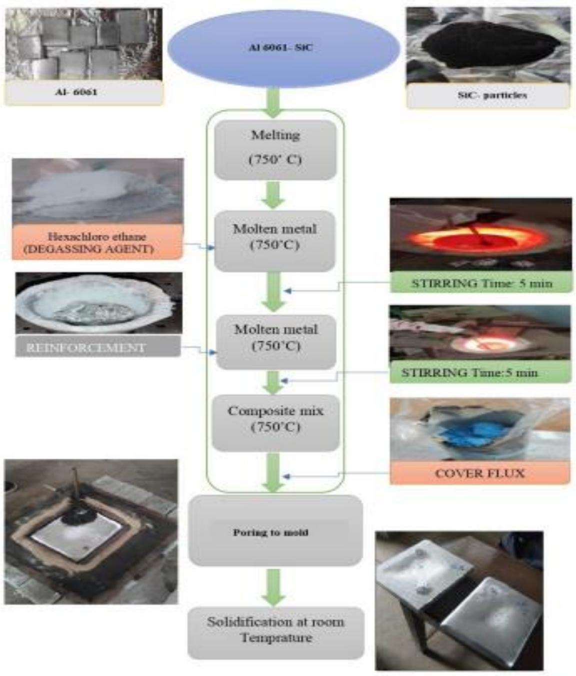

Figure 4: Stir-die casting process

A degassing tablet composed of solid hexachloro ethane ($C2Cl6$) was added to the vortex to remove any remaining impurities, and slag was removed from the molten metal [29-30]. The preheated SiC particles were added into the vortex at a temperature of 725˚C, followed by mechanical stirring at 150rpm for 15 minutes. To enhance the wettability of SiC, a wetting

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agent known as K2TiF6 was used during its addition to the melt. Prior to pouring the molten metal into the mold, a cover flux consisting of NaCl (45%), KCl (45%), and NaF (10%) was added to the molten metal to minimize atmospheric contamination

3.5 Thermocouples & data acquisition systems

In the present work, K type chrome-alumel thermo-couples with wire diameter of 0.3mm enclosed in stainless steel sheath with MgO insulation were used for temperature measurement. The final diameter of the thermo-couples with insulation was 1.5 mm. Fig.5 shows the KType Thermo-couple. Mineral insulated K- type thermo-couples are inserted into the center of the mold cavity to measure the time – temperature history of the mold is recorded during pouring and subsequent solidification. Agilent 34972A Data Acquisition Instrument was used for recording the time temperature history and it was Configured with a 16-channel relay multiplexer and offers 6 1/2 digits of resolution and 0.004% of accuracy. The 34972A automatically builds a scan list that includes all configured inputs (even digital inputs from the Agilent 34972A multifunction module) in ascending order by channel number, and it can pace scans by setting the 34972A's internal timer for automatic scanning at a specific interval [31].

Figure 5:K-type thermocouples for measuring temperature

4. RESULTS & DISCUSSION

The research was conducted to fabricate the composite comprising of Al as the matrix and SiC particles as the reinforcement (size 40-50 μm). The reinforcement being supplemented varies starting from 3 to 12 wt.% in step-ladders of 3 wt.%. The resultant composite was cast in sand mould patterns comprising chill blocks (DCT Copper and regular copper) remained verified for their material properties.

4.1Effect of micro structure bonding

The micro-structure indicates that coarse grains are obtained on the specimens portrayed with CU chill and fine grains are observed in the specimens portrayed by DCT-CU chill plates. comparison of the micro-structure on the side of CU Chill plate also indicates that DCT-copper

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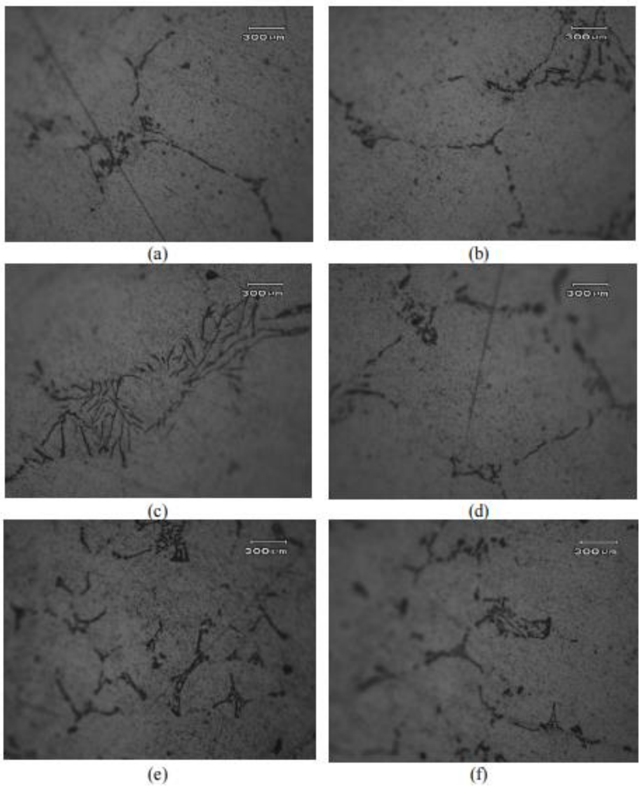
chill gives rise to very fine grain size whereas CU chill yields coarse grain size. CU chill Plate give rise to medium size grains. This can be attributed to the Chilling effect they induce during casting. It may be noticed that the thermal conductivity of DCT- CU is high (401W/m^{o}K) which leads to high cooling rate of pro near its vicinity. High cooling rate leads to fine grain structure as seen in Fig.6a to Fig.6j whereas the thermal conductivity of CU(390W/m^{o}K) leads slower cooling rate thus leads to coarse and medium grain structure [32].

4.2 Effect of tensile strength & elongation

A computerized UTM testing machine was used to conduct a tensile strength test on aluminum specimens and composites. The ultimate tensile strength (UTS) of discontinuously reinforcing composites is influenced by several complex and interrelated factors.The distribution and quantity of particles in the matrix, as well as the mechanical and physical properties of both the matrix and reinforcing particles, and the bonding between them are all reported to have a strong impact on the composite's strength [33]. Moreover, various mechanisms for strengthening have been proposed to explain the improved strength of discontinuously reinforced metal matrix composites (MMCs). To observe the variations in results, the average of five values was plotted.



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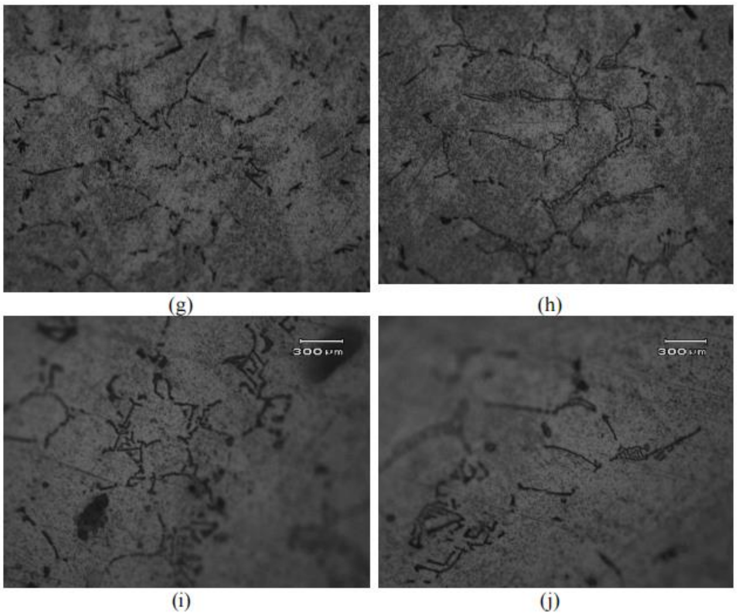

Figure 6:SEM images of (a-b) as cast,(c-d)Al+3%SiC,(e-f)Al+6SiC,(g-h)Al+9%SiC,and (i-j)Al+12%SiC

The results indicate that in Al-SiC composites, the ultimate tensile strength (UTS) of the composites increases monotonically as the particulate content is increased. This is attributed to the increased area of bonding at the inter-facial region between the matrix and reinforcement [34].

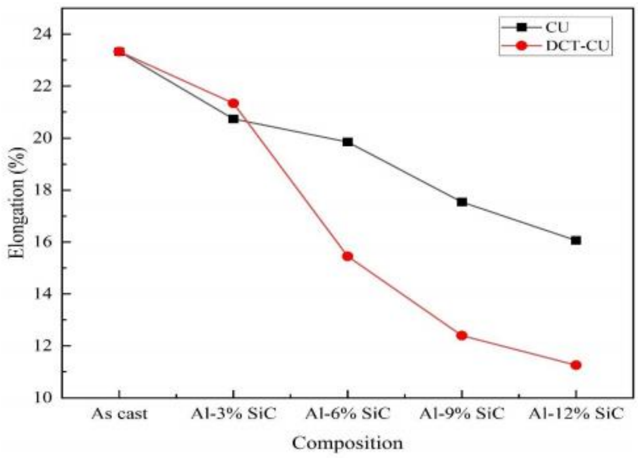

Figure 7:%elongation versus variation of compositions

Other researchers have also reported that adding ceramic particles to aluminum alloys improves their strength, wear resistance, and hardness. Fig.7 shows that %elongation versus

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compositions. The results obtained from the tensile strength test indicate that the Al-SiC composites produced through DCT-CU chill casting have better strength compared to pure aluminum cast regular copper chill.

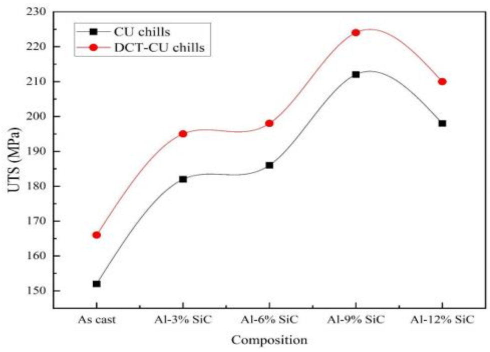

Figure 8: Tensile strength versus variation of compositions

The graph illustrates that adding SiC particulates to the matrix material enhances the strength of the matrix alloy by effectively resisting tensile stresses. Moreover, it was observed that the maximum tensile strength for Al-SiC composites was obtained for specimens cast with a DCT copper chill, while it was minimal for CU- chill. Fig.8 shows that tensile strength versus compositions.

4.3 Effect of hardness & compressive strength

The hardness studies have indicated that the Al-SiC composites produced through chill casting done by using DCT-Chills exhibit higher hardness compared to as cast with Regular CU-chill. The maximum value of hardness is observed in composites prepared by using DCT cu chill plates because of its fine grain structure due to freezing during solidification of the melt and moderate hardness was observed in the CU-chilled composites.The impact of percentage SiC concentration and chilling on the compressive strength of composite materials is depicted in Fig.9 It can be demonstrated that when the reinforcing material rises, the compressive strength of the composite as a whole grows monotonically. The increase of hardness is due to the increased area of bonding at the interfacial region of the matrix and the reinforcement and also refinement of grain structure [35]. Also, increase in hardness can be attributed to the addition of SiC particles which impart strength to the matrix alloy they're by enhanced resistance to crack or penetration. Fig.10 shows that harness versus variation of compositions.

5. CONCLUSION

The microstructure pictures clearly show that specimens cast with DCT-CU chill plates show small grains, while specimens cast with CU chill show coarse grains. It is further confirmed by comparing the microstructures on the Cu chill side that the DCT-copper chill yields much finer grain sizes than the CU chill, which produces coarser grains.

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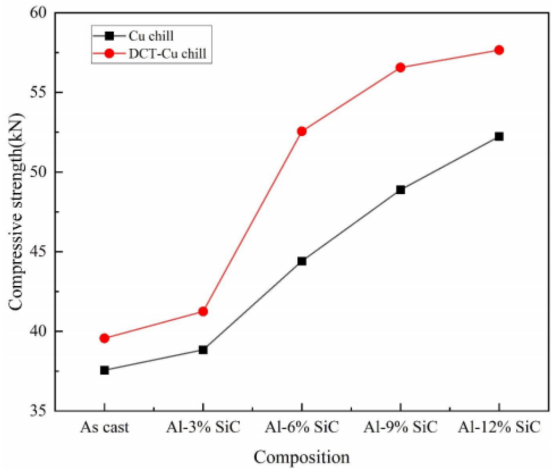

Figure 9: Compressive strength versus compositions

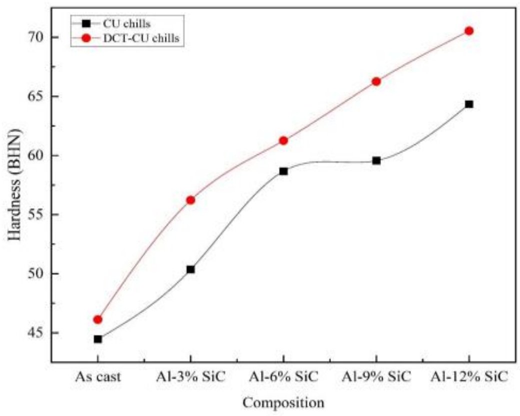

Figure 10: Hardness versus compositions

The composites made of Al-SiC that were cast using DCT copper chilling showed the highest tensile strength. This suggests that the optimal dispersion and bonding of SiC particles within the aluminium matrix are achieved using the DCT method in conjunction with copper chilling, resulting in enhanced mechanical characteristics.Al-SiC composites made with DCT-Chills in chill casting are harder than those made with standard CU-chills. DCT-CU chills composites exhibit the maximum toughness due to its fine grain structure resulting from fast solidification. CU-chilled composites show moderate toughness. The increased hardness is due to improved bonding at the matrix-reinforcement contact and finer grain structures.

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