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Study on mechanical performance of silicon nitride, Snail Shell Powder and Rice Husk Ash reinforced aluminium7075 hybrid metal matrix composites

Ravi Kumar Nagula [a*], Dr. K. Vijaya Kumar Reddy [b]
[a]Research Scholar, Department of Mechanical Engineering, Jawaharlal Nehru Technological University Hyderabad, Hyderabad-500085, TS, India**,**
[b]Professor, Department of Mechanical Engineering, Jawaharlal Nehru Technological University Hyderabad, Hyderabad-500085, TS, India

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A B S T R A C T
In current study the effect of silicon nitride (Si_3N_4), Snail Shell Powder (SSP) and Rice Husk Ash (RHA) reinforcements on the mechanical behaviour of Al7075 composites are evaluated. Frequency based stir casting is used to fabricate distinct Hybrid Aluminium metal matrix composite compositions. The proportion of silicon nitride and snail shell powder in making composites is altered from 2 to 6 wt. percent with a step of 2 wt. percent and Rice husk ash with a constant 5 wt percent. Hardness, Tensile and impact measurements in accordance with ASTM standards are used to assess the reinforcement alterations in the mechanical properties of hybrid aluminium composites. The casted surfaces are observed with under an optical microscope, and the micrographs show that the generated composites have good filler and base mechanical interlocking and matrix compatibility of SSP, Si_3N_4 and RHA with aluminium alloy matrix. The observed results justify the use of above reinforcements to improve the mechanical properties of aluminum alloy hybrid composite systems for industrial light weight applications.

Introduction

Because of metal matrix composites (MMCs) outstanding wear resistance, fatigue strength, damping property, and expansion coefficient, MMCs are employed in automotive and aerospace applications[1]. Aluminum metal matrix composites (AMMCs) have resulted in the creation of new materials with increased temperature resistance, stiffness, and lightweight properties[2]. Light weight MMCs reinforced Silicon nitride has garnered interest due of their increased mechanical characteristics, economic effectiveness, and environmental benefits [3]. Similarly, it found the application in engine cylinder blocks and wheels for better castability parts in terms of size and shape [4].
Many studies [5–7] have found that adding ceramic particles to an aluminium matrix improves its mechanical characteristics. As a result, one of the major types of MMCs is aluminium reinforced with ceramic particles [8]. However, there are still issues with making superior reinforced hybrid MMCs. The main problems are to achieve a good quality bond between the matrix alloy aluminium and the reinforcement, to avoid/ minimize interfacial interaction between the base matrix and the particles of reinforcement, and to increase the wettability of the reinforcement particles in aluminum matrix material[9]. The interface has a considerable impact on the mechanical characteristics of MMCs because it influences the load transmission efficiency on reinforcement particles and matrix [10]. It has also been observed [11] that the interfacial interaction created at the contact reduces the mechanical characteristics of MMCs. According to several findings [12–14], coated metallic ceramic reinforcements such as Al2O3, SiC, TiO2, and graphite have superior wettability and adherence than uncoated ceramic particle reinforcements. Furthermore, coating ceramic particle reinforcements results in mild chemical interactions between reinforcement and matrix and increases interface strength, resulting in improvement of overall mechanical qualities. There is several researches in the literature that investigate the mechanical characteristics of Si_3N_4 or SiC reinforced aluminium composites. Powder metallurgy to create Al-SiC nanocomposites is used by Pakseresht et al.. The outcome of SiC constituting and milling duration on the

mechanical characteristics and Al-SiC composites microstructure have been studied. Vickers hardness number of Al-SiC metal composites rose as ball milling duration and SiC concentration increased [15]. Sharma et al. investigated the standard stir casting process for producing aluminium (AA6082-T6) metal matrix composites augmented with various weight percentages of silicon nitride Si_3N_4 particles. Mechanical parameters such as hardness and ultimate tensile strength increased at the expense of ductility as the percentage of weight of Si_3N_4 silicon nitride particles increased (ranging from 0-12 wt percent in an aluminium composite metal matrix [16].

Kumar et al. stir cast aluminium (AA2618) matrix composites reinforced with ZrB_2, Si_3N_4 and AlN particles (0-8 wt%). Increased AlN, Si_3N_4, and ZrB2 concentration improved the mechanical parameters of composites such as compressive strength, hardness, and tensile [17]. There are few articles on the influence of large-scale Silicon carbide SiC and Si_3N_4 amounts on the mechanical characteristics and microstructure of composites that are aware of. C.S. Ramesh et al. [18] used liquid metallurgy to create a Si_3N_4 reinforced Al6061 composite.

There is anticipation that around 70 X 10^6 tonnes of RHA are generated world wide each year [19]. RHA is a significant environmental danger, causing harm to the ground and the surrounding region where it is discharged. This guarantees that the researcher can make optimal use of the agricultural waste. As a result, the ecosystem is protected from these wastes. According to current research findings, RHA includes 85-90 percent amorphous silica[20-21]. Rice Husk (RH) has a larger amount of ash than many biomass fuels, and it contains 85-87 percent silica, indicating a high amount of porosity, reduced weights, and a large exterior surface area[22]. The AA-based matrix composite reinforced with fly ash and RHA was described by Narasaraju and Lingaraju [23].

According to D.Siva Prasad et al., observation, the hardness value of A356.2/RHA composites rises as the ash concentration of rice husk increases. The incorporation of RHA particles into an aluminium matrix can result in the creation of low-cost aluminium composites with increased hardness and strength. [24]. Md. Rahat Hossain et al. concluded that the mechanical properties of aluminium hybrid composites increased by increasing percentage of RHA in the hybrid composites, with the exception of reduction in area property with elongation, which decreased with increasing percentages of RHA content. The use of RHA in the fabrication of cost-effective aluminium metal composites might have increased hardness and strength. [25]. Soutrik Bose et al. created a hybrid metal composite by adding it with snail shell ash SSA, boron carbide, cow dung ash and waste egg shell and discovered that the particle reinforcements are non-reactive, steady at elevated temperatures, and have improved tribo mechanical characteristics [26].

T. B. Asafa[27] used stir casting to create Aluminium composites AMMC's reinforced with SSP snailshell particles SSP with weight fractions from 16-48 wt. percent and sizes ranging from 200, 400 and 600 m. The tensile strength noted as 236 MPa and the hardness noted as 48.3 HRF at 48wt. percent and 600 m particle size, respectively. Through stir casting, Omole, Sylvester O [96] produced Aluminium Al6063 alloy composites supplemented with 150 m walnut powder with weight percentages of 3%, 5% &7%. The hardness calculated is high at 7% reinforcement, with a value 113.6 BHN, and the tensile characteristics are also improved when compared to other composites. Calcium carbonate exits naturally and is usually found inside biological sources such as freshwater mussel shell, seashells, clams, snail shell, and eggshell [26]. However research on the use of snail shells SSP in the hybrid metal matrix composite has been reported rarely.

Based on the review of literature, lot of experiments was carried on the ceramic particle reinforcements such as tungsten carbide, silicon carbide, and alumina as reinforcements. It is anticipated that there was little experimental study carried out with snail shell powder and silicon nitride as reinforcement. As a result, an attempt is made to investigate impact of Si_3N_4, snail shell powder SSP, and constant weight % rice husk ash RHA-based hybrid composites on mechanical behaviour.

1. *Methods*

The stir casting method is chosen to make the Hybrid metal matrix. Stir casting required 2 steps: melting the alloy metal and adding the reinforcement with the molten metal. At the beginning, the base material Al7075 and reinforcement's silicon nitride, snail shell powder, rice husk ash with varying weight percentages are bought. Aluminium cut pieces are added to crucible for stir casting process in an induction based heating furnace. The Al-7075 base alloy weight is calculated based on the size of the die used and melted in graphite crucible at 710 °C. After being heated to a molten condition, the molten alloy is stirred by frequency based stirring and degassing agent is added in order to eliminate any gases. Pre heated reinforcements are added to the molten alloy and stirred for 15 minutes before being put into the flat cast iron die and allowed to solidify. The die is allowed to cool down to room temperature before cutting the specimens to required dimensions for performing the tests. The continual mixing of the liquid resulted in the homogenous dispersion of reinforcement particles. The same technique is followed for the various compositions given in Table 1.

Table 1

Fabricated compositions

Sl.No.	Specimens	Al6061 (wt %)	Reinforcement (wt %)		
			Si_3N_4	SSP	RHA
1.	Al7075	100	0	0	0
2.	S1	91	2	2	5
3.	S2	87	4	4	5
4.	S3	83	6	6	5

2. *Experimental*

3.1 Tensile strength

Tensile test is conducted to determine Ultimate Tensile Strength (UTS) and Yield Stress of Al7075 composites. The tensile test is performed on a Universal testing machine using an ASTM E8 standard flat specimen. The test is run in mode of displacement control, with the crosshead speed set to 2 mm per min. All of the specimens are held using mild steel jaws. The gauge length is 27mm with a thickness of 6.25mm. The sample is exposed to a progressive increase in axial force until fracture occurs. Note the load that corresponds to the deformation. The procedure is done three times for three distinct trials and composite specimens (Table 2).

Table 2

Tensile Test results

Sl. No	Specimen	Composition	Ultimate tensile strength (N/mm^2)	Yield Stress (N/mm^2)	Percentage of Elongation (%)
1.	Al7075	Pure 7075	129.582	52.146	10.81
2.	S1	Al7075+ 2%Si_3N_4+ 2%SSP+ 5%RHA	117.604	47.44	5.546
3.	S2	Al7075+4 %Si_3N_4+ 4%SSP+ 5%RHA	145.394	58.52	15.106
4.	S3	Al7075+ 6%Si_3N_4+ 6%SSP+ 5%RHA	154.64	62.169	8.21

3.2 Hardness

For the specimens, hardness according to standards of ASTM, the Rockwell hardness tester is used. The Rockwell hardness machine assesses hardness by comparing the indenter depth of penetration under a heavy load to that of a preload. The primary advantage of Rockwell hardness is its ability to immediately display hardness values, avoiding the lengthy computations required by other hardness measuring systems. The Rockwell hardness of a material is determined by applying a mild force followed by a major load. When the primary load is released, the dial indication displays the Rockwell hardness number (HRB).

The intensity reading of the indent's penetration is used to define the hardness value of the

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indentation in contrast to indenter penetration. The hardness values are collected at five separate locations (Table 3) and the average of values is shown.

Table 3

Hardness

Sl.No	Sample	Test number	Load applied (Kgf)	Dia. of Indenter	Scale	Rockwell hardness number (HRB)	Mean (HRB)
1.	Al7075	1, 2, 3, 4, 5	100	1/16”	B (Red)	60,67,64,67,72	66
2.	S1					75,79,79,76,84	78.6
3.	S2					73,59,66,50,50	59.6
4.	S3					77,63,64,70,61	67

3.3 Impact strength

The impact strength test is carried out using an impact testing equipment using the IZOD technique in accordance with standards and dimensions of ASTM. Table 4 shows the energy absorbed during its breakdown by the material. The amount of reinforcements applied to the matrix material determines the toughness value of hybrid metal composites.

One of the most highly recommended mechanical features of industrial materials is impact behavior. The solid interface and sound mechanical integrity between the Al and the subordinate content, which can transport the load from the primary alloy to the reinforcing content, might be attributed to the increase in impact strength.

Table 4

Impact strength

Sl.No	Sample	Composition	Impact Energy (J)	Impact Resistance (J/mm^2)
1.	Al7075	Pure Al7075	2.0	0.025
2.	S1	Al7075+ 2%Si_3N_4+ 2%SSP+ 5%RHA	3.0	0.0375
3.	S2	Al7075+4 %Si_3N_4+ 4%SSP+ 5%RHA	12	0.15
4.	S3	Al7075+ 6%Si_3N_4+ 6%SSP+ 5%RHA	8.0	0.1

3.4 Micrographic analysis

The composite surfaces of the fractured impact test samples are examined using an optical microscope. In this study, computerized Image capture software is used for the capturing material characterization of composite surface. Unreinforced and hybrid composite test samples are extracted from cracked impact specimens and ground with abrasive sheets before being polished with a spinning disc cloth. Keller's reagent (50 mL water, 25mL HNO^3, 15mL HCl, 10mL HF), a commonly used general purpose reagent for Al and Al alloys, is utilised as the etching agent. Microscopic images of different casted specimens with Si_3N_4, SSP and RHA reinforcements (S1, S2, S3) with Aluminium and pure Al7075 unreinforced specimens are characterized with an image magnification of 100× and 200×.

4. Result

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4.1 Hardness

Rockwell hardness values of Aluminum along with various weight fractions of Si_3N_4, SSP, RHA are presented in Fig. 1. The hardness number HRB reveals that there is raise in hardness values with raise in reinforcement's content. When compared to Al7075, Al7075+ 2%Si_3N_4+ 2%SSP+ 5%RHA and Al7075+ 6%Si3N4+ 6%SSP+ 5%RHA alloys improved their Rockwell hardness numbers by 19.09 and 1.51 percent, respectively, while Al7075 + 4%Si_3N_4+ 4%SSP+ 5%RHA percent HRB declined by 9.697 percent. The presence of reinforcements causes dramatic variations in the hardness number of composite matrix materials. The presence of porosities in the material reduces its hardness rating. It should be noted that the inclusion of ceramic nature fillers tends to enhance the porosity of the alloy material. Raising the particle weight of the additives, on the other hand, tends to diminish porosities, hence increasing the hardness value. Furthermore, extended Stirring at high frequency might produce a rise in porosities that tend to impact the static related mechanical properties of the composite matrix material by functioning as possible stress concentration areas making optimal stirring a must. The hardness of the material improves with increasing reinforcement weight percentages, as predicted. The maximum improvement in hardness is observed with S1 (Al7075+ 2%Si_3N_4+ 2%SSP+ 5%RHA) and exhibits better hardness as 78 HRB compared with other produced composite samples.

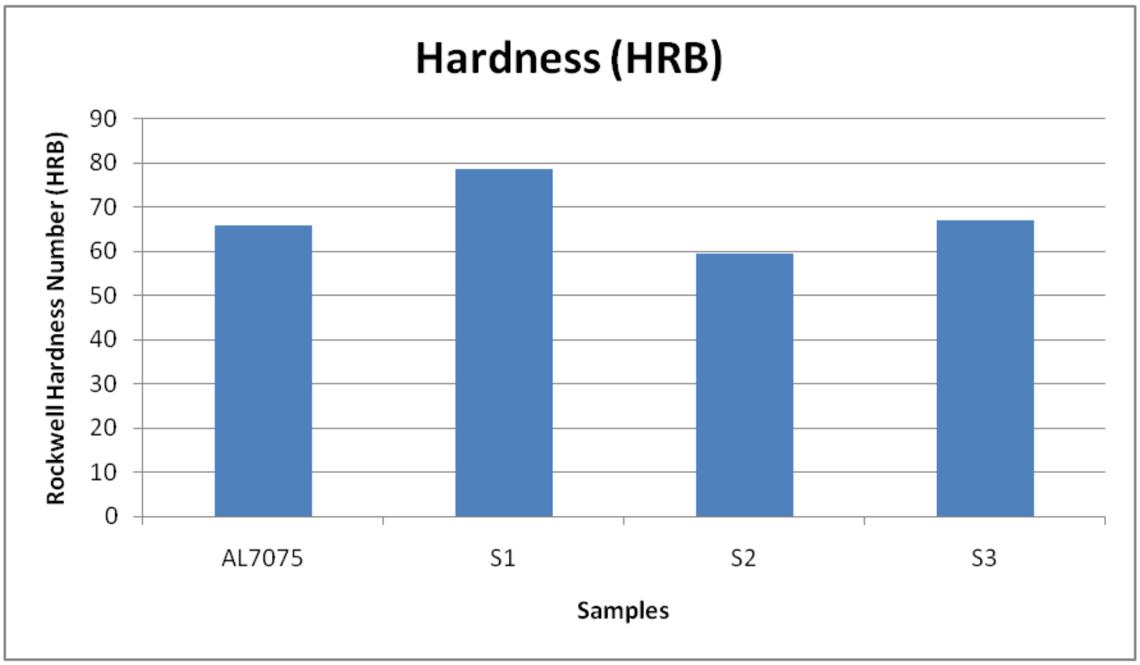

Fig. 1. Comparison of Rockwell hardness number

4.2 Tensile result

Fig. 2 displays the values of the obtained tensile strength at ambient room temperature. Interpreting the graph it is revealed the addition of Si_3N_4, SSP & RHA content enhances the ultimate tensile strength of the composites. The tensile strength value rise from 129.58 MPa to different values in this case for Al-based hybrid composites. This explains that by introducing Si_3N_4, SSP & RHA into the Aluminum metal matrix enhances the material properties because of better compatibility and maximum interfacial adhesion between reinforced particles and hybrid Aluminium matrix. When compared to pure Al7075, S3 (Al7075+ 6 percent Si_3N_4+ 6 percent SSP+ 5 percent RHA) improved tensile strength by up to 19.63%.

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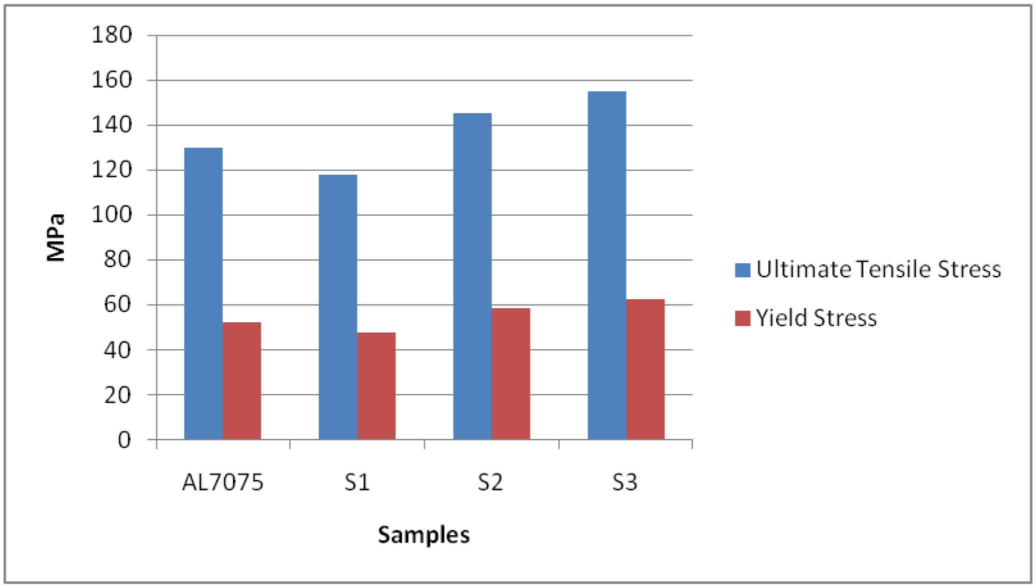

Fig.2. Ultimate tensile strength

4.3 Impact Test

It is discovered that all of the produced composite prepared specimens have higher impact resistance than pure Al7075. When a practical consequence, as the Si_3N_4 reinforcing material is increased, the composites impact strength rose linearly. The impact strength of the specimens with 4 wt. % Si_3N_4 & SSP integrated AMCs is greater. Furthermore, ductility is reduced owing to grain refinement, but impact strength is significantly increased due to load transmission from the matrix to the reinforcing component. Fig. 3 shows that the impact resistance of produced composite samples S1, S2, and S3 improved by 50%, 500%, and 300%, respectively, when compared to Al7075. The findings show that the toughness of produced composite samples increased as the nature of the reinforcing particles changed. When compared to pure Al7075, S2 (Al7075+4 percent Si_3N_4+ 4 percent SSP+ 5 percent RHA) improved impact resistance by up to 500%.

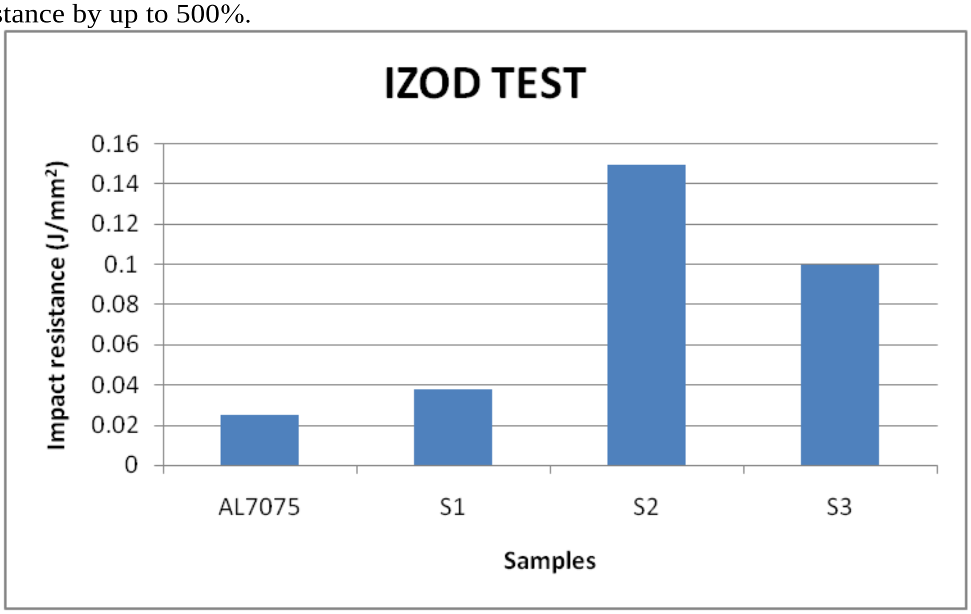

Fig. 3. Comparison of Toughness

4.4 Micrographic observation

The optical metallurgical microscope is used to examine the microstructure of composite specimen surfaces. Specimen is prepared and cut in accordance with normal metallographic procedures. After Si_3N_4 assimilation, the mechanical characteristics of Al7075 improved. It is discovered that the hardness of hybrid AMCs increases linearly with rise in fractions of weight of Si_3N_4 particles. This might be attributable to a rise in the prevalence of hard Si_3N_4 particles in the aluminium matrix, as well as the Si_3N_4 particles high hardness. The incorporation of particulate reinforcement into the aluminium metal matrix increases their surface area while decreasing aluminium matrix grains size. The presence of Si_3N_4 particles hard surface regions provides significant plastic deformation resistance, resulting in an increase in the hardness of manufactured AMCs.

Furthermore, the presence of brittle and hard Si_3N_4 in the ductile and soft Al7075 base decreases the content of ductility in fabricated hybrid AMCs due to the low ductile percentage of base metal in the hybrid composite, which significantly improves manufactured AMC hardness. Due to presence of thermal mismatch between the reinforcement and aluminium matrix, higher reinforcement particle in the base matrix alloy leads to increased density dislocation while solidification. Increased density dislocation at the particle base matrix contact, results in increased plastic deformation resistance, resulting in increased hardness. As a result, the microstructural properties of the matrix alter, contributing to the matrix's increasing strength.

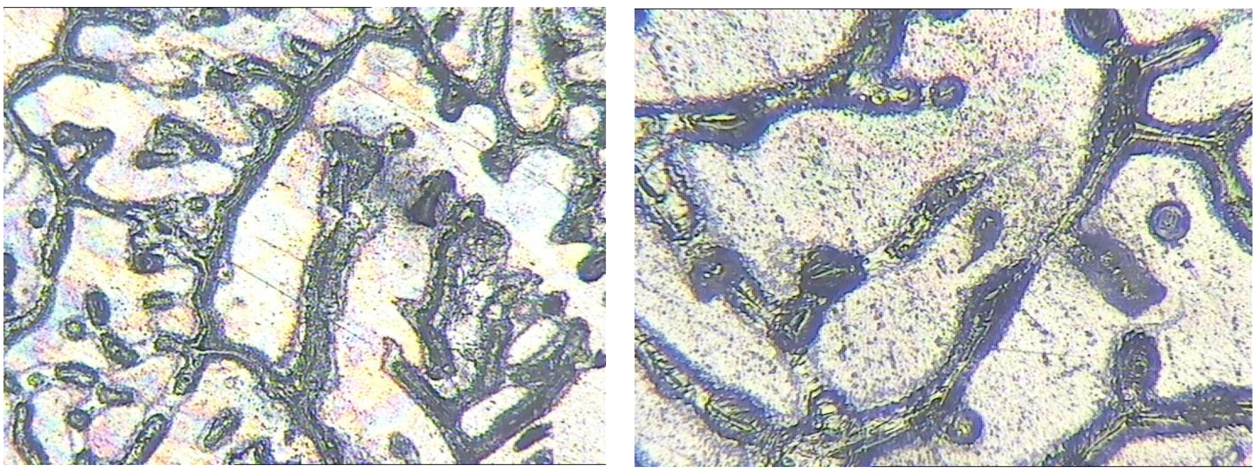

Fig.4. Micrographic photographs of specimen pure Al7075 (a) 100× (b) 200×

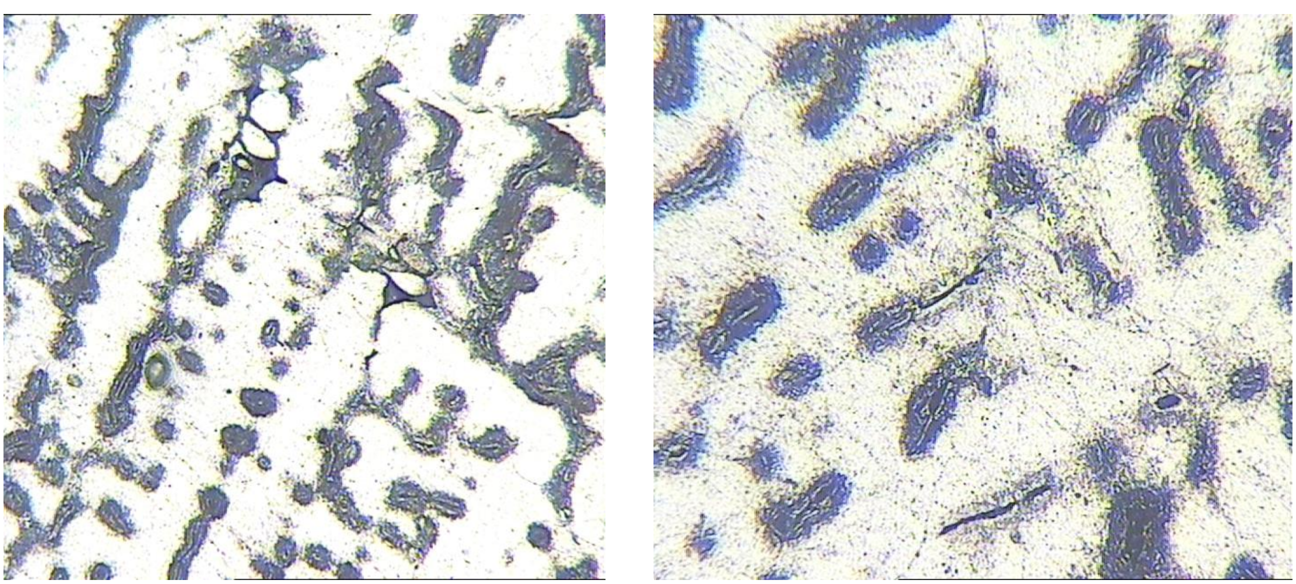

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Fig.5. Micrographic photographs of specimen Al7075+ 2%Si_3N_4+ 2%SSP+ 5%RHA (a) 100× (b) 200×

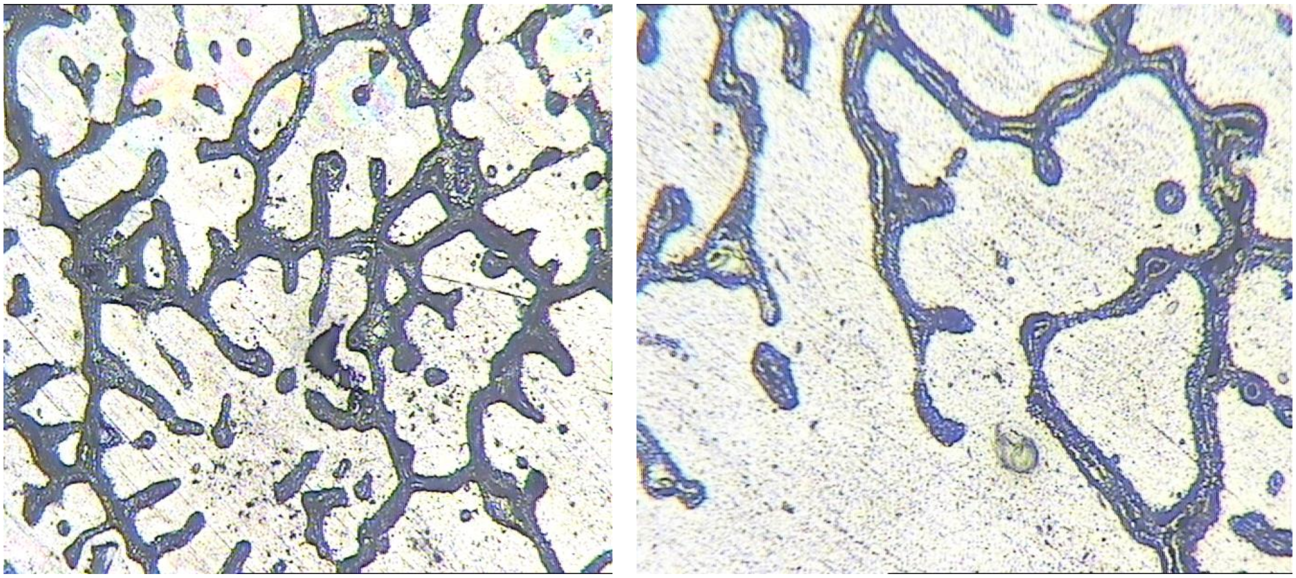

Fig.6. Micrographic photographs of specimen Al7075+ 4%Si_3N_4+ 4%SSP+ 5%RHA (a) 100× (b) 200×

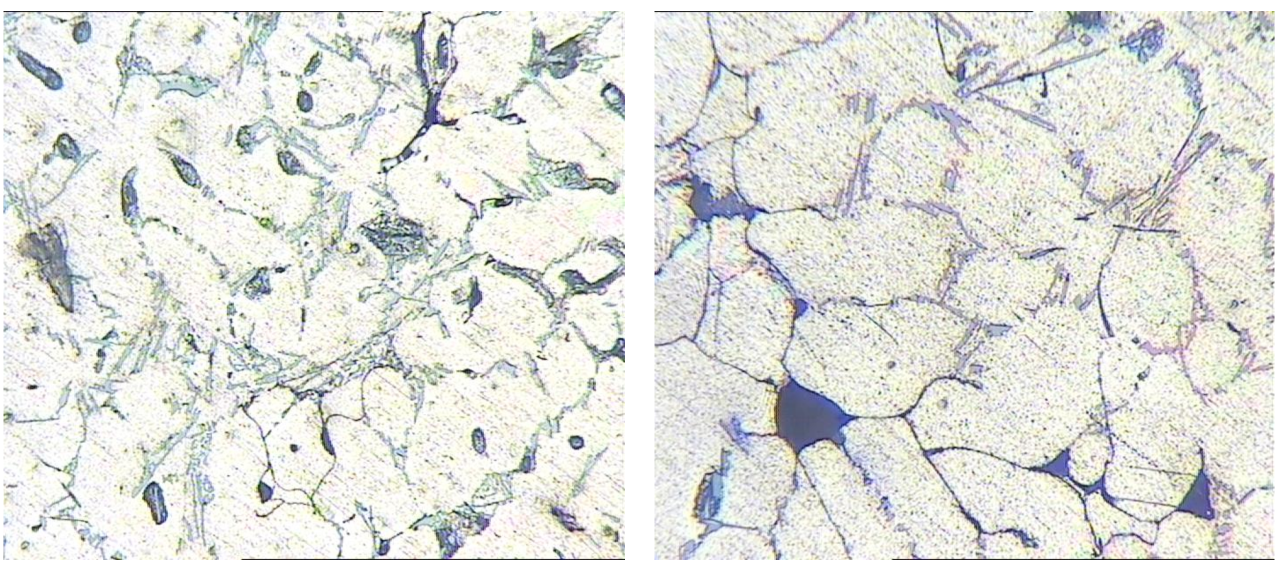

Fig.7. Micrographic photographs of specimen Al7075+ 6%Si_3N_4+ 6%SSP+ 5%RHA (a) 100× (b) 200×

The microstructure is made up of silicon distributed in the interdendritic region and smooth precipitates of alloying particles in an aluminium composite matrix. Figure displays casted aluminium with varying reinforced composites. It demonstrates that a homogeneous distribution of matrix and reinforcement results in fewer agglomerations. Several filler structures may be seen. Agglomeration will occur as a result of heavy reinforcement loading in material matrix, which can reduce material characteristics.

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The pictures indicated the appropriate RHA dispersion in the composite, as well as some clustering particle in the matrix. The presence of oxygen and silicon demonstrates that silica is dispersed in RHA. It can detect grain boundaries, orientations, and dispersion. As a result, a quantitative link may be established between composite grain boundary orientation and structure parameters. Particles of RHA act as a boundary to the development of aluminium grains. RHA particles act as nucleating for grains sites, and grains of aluminium tend to develop on them. Around the RHA particles the temperature falls, causing an undercooling effect. This increases the nucleation sites number in the casting wherever particles of RHA are present. The barrier to aluminium grain development rises as the number of nucleation sites increases. As a result, the grains in the composites are refined.

In the hybrid composite the presence of snail shells powder (Snailshells are made up of CaCO3) in the calcite form, which highlights the presence of calcium. Furthermore, the filler particles are evenly dispersed. The SSP's distribution is determined by the wettability of the SSP's by molten aluminum metal and the particle-matrix material interfacial bonding.

5. Conclusions

The conclusions can be taken from the aforementioned test results:

- Frequency based Stir casting is an appropriate process for casting Al composites because it results in a consistent primary particles distribution in the material casted.

- The tensile strength and hardness test results reveal that the material's strength has risen with the addition of reinforcements Si_3N_4, SSP & RHA.

- When compared to pure Al7075, S3 (Al7075+ 6 percent Si_3N_4+ 6 percent SSP+ 5 percent RHA) improved tensile strength by up to 19.63%. Tensile strength enhances material characteristics due to improved interfacial adhesion and compatibility between reinforced particles and the aluminium hybrid matrix.

- The maximum improvement in hardness is observed with S1 (Al7075+ 2% Si_3N_4+ 2%SSP+ 5%RHA) and exhibits better hardness as 78.6 HRB compared with other fabricated composite samples. Raising the particle weights of the additives, on the other hand, helps to reduce porosity and hence increase the hardness value.

- When compared to pure Al7075, S2 (Al7075+4 percent Si3N4+ 4 percent SSP+ 5 percent RHA) improved impact resistance by up to 500%. As the nature of the reinforcing particles varied, the toughness of the resulting composite samples increased.

- Based on optical imaging, it is inferred that the process has a homogeneous distribution of primary particles.

- In composite, significant grain refinement has been seen. Composites have better ultimate tensile strength, hardness, and yield strength than matrix alloys.

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