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Investigational studies on characteristics of Nano Silicon Nitride Incorporated AA8050 composites

Aman Sharma[1], Nagabhooshanam Nagarajan[2], Suresh Kumar Srinivasan[3], Sathish Kannan[4], Manzoore Elahi Mohammad Soudagar[5,6,7], Ahmed Fouly[8], Asiful Hossain Seikh[8]

[1]GLA University, Department of Mechanical Engineering. Mathura, Uttar Pradesh, India.

[2]Aditya University, Department of Mechanical Engineering. Surampalem, Andhra Pradesh, India.

[3]T.J.S. Engineering College, Department of Mechanical Engineering. Peruvoyal, Tamil Nadu, India.

[4]Saveetha University, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Department of VLSI Microelectronics. Chennai, Tamilnadu, India.

[5]Lishui University, College of Engineering. Lishui, Zhejiang, China.

[6]Chitkara University, Chitkara University Institute of Engineering and Technology, Centre for Research Impact and Outcome. Rajpura, Punjab, India.

[7]Lovely Professional University, Division of Research and Development. Phagwara, Punjab, India.

[8]King Saud University, College of Engineering, Department of Mechanical Engineering. Riyadh, Saudi Arabia.

e-mail: sandysureesh2022@gmail.com, aman.sharma@gla.ac.in, nnagabooshnamaditya@hotmail.com, sathishk.dr@outlook.com, me.soudagar@gmail.com, afouly.mech@outlook.com, asifulhs.dr@hotmail.com

ABSTRACT

This current work, studied the effects of nano silicon nitride (n-Si_3N_4) particles incorporated with AA8050 matrix using a stir-casting method. Physical characteristics including density and porosity were measured. The mechanical characteristics including the impact strength (IS), ultimate tensile strength (UTS), elongation (El), and Vickers hardness (HV) were evaluated according to the standards. Metallurgical characteristics including Scanning Electron Microscopy (SEM), Energy dispersive spectroscopy (EDS) and X-ray diffraction analysis (XRD) examined the synthesized composites. The theoretical density rise for 3.5% reinforcement is capped at 1.6%, while the experimental density drop is 3.1%. Also incorporating n-Si_3N_4 into the matrix significantly increased the UTS, HV, and IS with a percentage of 11.04%, 25.88%, 29.88% accordingly. SEM of AA8050 Composites revealed a dispersion of n-Si_3N_4 particles in the AA8050. When analyzing the EDS of AA8050 Composites, a high-intensity peak indicates that the composites have a high rate of Al by weight. In XRD to all appearances, the Al phase encloses the n-Si_3N_4 particles.

Keywords: AA8050; Nano silicon nitride; Physical properties; Stir casting; Vickers micro hardness.

1. INTRODUCTION

Composites are comprised of components that have been bonded together in order to give a specific property. It is vital to integrate reinforcements with the matrix in a suitable manner in order for composites to be able to accomplish the function for which they were designed. Several different kinds of matrix material can be broken down into the categories. Depending on the kind of reinforcement that is incorporated into the composite material, there are unique types of composite materials that can be differentiated from one another [1, 2]. The reinforcement of matrix-metal-composites (MMCs) hence constitutes the discontinuous phase that homogenizes with the matrix. Compared to the continuous phase, it is typically more robust and complicated. In this way, MMCs is lighter than the base metal or alloy it is made from while still maintaining its hardness and strength. MMCs are the outcome of the fusion of different ceramic particles into metal matrix composites. It has ceramic particles of two or more types interspersed with metal atoms. As a result of their portability, low price, and high usability, MMCs have gained significant popularity in recent decades. Investigations are ongoing to advance the development of MMCs for individualized dwellings. Manufacturing composites by evenly spreading components like nitrides, carbides, oxides, and borides throughout a matrix and then characterizing the resulting material is one way to achieve this end [3–5]. Common matrix metals include aluminum, magnesium, copper, and others. Because of its low density and relatively cheap, aluminum is the most popular matrix

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material. In comparison to the less desirable qualities of the base metals, the MMCs are more desirable for use in engineering. The majority of the most recent advancements in the uses of MMCs have concentrated on structural components and wear resistance. These applications have been taken into consideration to their full extent [6].

Si_3N_4 particles are manufactured by electrochemically reacting carbon and sand at high temperatures. Si_3N_4 particles potential to enhance MMCs characteristics depends on the composite's final makeup. The contact between the Si_3N_4 particles and the base alloy may significantly impact many properties. Even the dispersal of elements in the alloy is the most crucial need for producing superior MMCs. Particle agglomeration is a significant problem during MMCs production, significantly impacting the properties of material [7–9]. It is anticipated that composites will continue to find new uses; however, the large expansion of the market for these materials will need the development of processing technologies that are on the lower end of the price spectrum as well as the potential of recycling. Fabrication methods for MMCs have been the subject of several reports. Processing techniques, such as stir casting, squeeze casting, compo casting, and infiltration, etc., are used in synthesizing MMCs [10, 11]. To increase the wetness in aluminium MMCs, we investigated the effects of stirring properties, wetting agent (Mg), and reinforcement percentage. Any additional magnesium increases the slurry's viscosity, which disrupts the intended uniform dispersion of the reinforcement [12, 13]. To create AA7068/n-Si_3N_4 nanoparticles of ratio 0.5, 1, 1.5, and 2%, MMCs in a liquid, the author created a unique design for stir casting arrangement with bottom pouring setup and ultrasonication for synthesization [14]. By increasing the reinforcing fraction of Si_3N_4 particles the MMCs hardness and UTS increases. There is a positive correlation between the fraction of reinforcing material with the porosity and density. It observes that the MMC's hardness have increased while the porosity has decreased. Castings in a semisolid state results in more excellent wettability and particle distribution of particulates, and concluded that it is preferable to casting in a completely liquid form [15–18]. Stir-casting Aluminium 2024/Si_3N_4/lithium particles composites were examined. Density is reduced as reinforcing percentage increases with the combinations. The microstructure photos indicate that the reinforcement was equally disseminated. Impact Strength and hardness were found to improve with the reinforcing percentage [19]. Reinforcing n-Si_3N_4 particles (5wt.%) and Graphene (particle size 8–15 nm, 0.5 to 1.5wt. % into base Aluminum alloy, planned to boost the MMCs strength while concurrently decreasing its weight. SEM was utilized to investigate fabricated samples for evidence of reinforcing material mixing. Al, Si_3N_4, SiC and GP may all be seen as prominent peaks in the XRD [20, 21].

The author investigated the microstructure of Al-356/Si_3N_4 composites (10, 20 and 30% by weight). Microstructural features were studied. The strengthening particles are engrained in the mixture and spread uniformly all through the blends [22]. The Al-7075/ 8% Si_3N_4 composite with 0 to 6% graphite was made by stir casting. According to the results presented in this research, these blends might be prospective nominee elements for different sliding industries, notably in the engineering industries It was found that the surface forms an oxide layer that protects it from wear up to a particular transition load [23]. For use in sectors like computing and automobiles, where components are often heated to extremes of temperature, thermal assessment of components is crucial, especially composites like Al/Si_4N_4. Conventional approaches to studying thermal properties have relied on laborious and narrow experimental procedures. Authors observed a 23.33 percent improvement in thermal conductivity and a 20.73% reduction in the coefficient of thermal expansion. Aluminium augmented with Si_3N_4 exhibited better thermal performance compared to aluminium with no augmentation [24, 25]. n-Si_3N_4 particles have been studied extensively for their potential to strengthen aluminum MMCs. The literature shows a range of 0–10% reinforcement producing the most favorable outcomes. As the reinforcement's weight fraction rises, the material's mechanical properties tend to improve. However, with a higher weight percentage, the results begin to deteriorate [26, 27]. The proposed research focuses on making AA8050/n-Si_3N_4 particles composites and characterizing their physical, mechanical and metallurgical properties through various testing approaches following standards for their applicability in engineering environment.

2. EXPERIMENTAL DETAILS

AA8050 used in many industrial applications, offers exceptional qualities and exhibits high corrosion-resistant characteristics but also possesses excellent strength, allowing for easy modification into any desired form holding potential for use in the bodybuilding industry [28]. This study takes n-Si_3N_4 reinforcement particles and used them in varying proportions of 1.5, 2.5 and 3.5% n-Si_3N_4 in an AA8050 to make composites. Table 1 displays the chemical components of AA8050.

Table 1: AA8050 compositions.

ELEMENTS	Cu	Fe	Mg	Mn	Si	Zn	Al
Wt%	4.2	0.40	0.15	0.80	0.09	0.1	Bal

AA8050 alloy served as the matrix for the composites, which were then reinforced with n-Si_3N_4 particles in varying concentrations. The n-Si_3N_4 particles as depicted in Figure 1 is reinforced with composites with specimen code with varying reinforcement percentages are debited in Table 2.

Stir casting system in which the molten metal is poured from the bottom into the cast iron mold. In the crucible, bits of AA8050 were progressively heated to about 780°C. Preheating the required amounts of n-Si_3N_4 particles to 350°C for 30min in a muffle furnace improves wettability between the reinforcement and AA8050. The mechanical stirrer maintains a constant speed of 350 revolutions per minute while n-Si_3N_4 particles are slowly added to the molten AA8050. The purpose of this operation is to ensure that the particles that are responsible for the production of composites are distributed evenly. This process is repeated until the melting temperature is reached [29]. Mold has been prepared at 250 °C for 1 hour, and poured the molten AA8050/ n-Si_3N_4 into molds from the furnace. After proper setting, it is removed from the mold for the preparation of the specimen as per standards.

2.1. Physical properties (density and porosity)

The composites density after being made is a good indicator of the effect of the reinforcing proportions taken. The rule of mixtures is used for evaluation of the theoretical density of the samples. At room temperature, the composites experimental density can be determined by measuring its mass and volume of AA8050/n-Si_3N_4 composites. The samples' masses are selected with precise electronic weighing equipment. It is usual for composites to have some porosity. The characteristics of composites are affected by porosity. The porosity or void content is calculated by comparing the AA8050/ n-Si_3N_4 composites theoretical density (r_{th}) with their experimental density (r_{exp}).

2.2. Mechanical properties (UTS, EL, HV, IS)

The mechanical properties of AA8050/n-Si_3N_4 composites depend on several factors, including the temperature, reinforcement quantity, particle size, and the distribution of the reinforcement within the matrix. The tensile

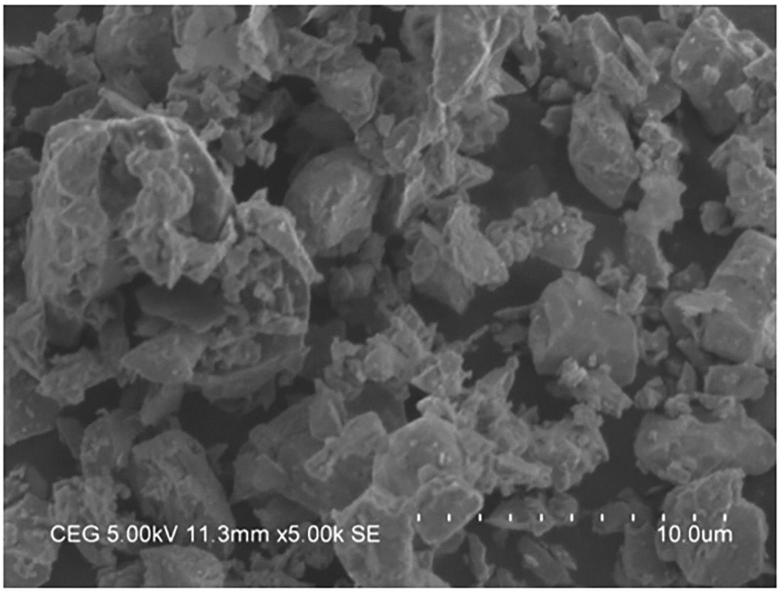

Figure 1: Scanning Electron Microscope image of n-Si_3N_4.

Table 2: Description on the composites of AA8050/n-Si_3N_4.

SPECIMEN CODE	COMPOSITION OF SPECIMEN
A	AA8050+0% n-Si_3N_4
B	AA8050+1.5% n-Si_3N_4
C	AA8050+2.5% n-Si_3N_4
D	AA8050+3.5% n-Si_3N_4

sample was manufactured as per ASTM E8 standards using wire cut EDM. A computerized UTM was used to measure the material's UTS and El. The composites' micro hardness is measured using specimens prepared following the standards ASTM E384. The Vickers hardness was measured in this work by the load of 0.5 Kgf for a dwelling period of the 15s with a diamond indenter. Each specimen's hardness was assessed by averaging the results of five separate measurements to get reliable data [4]. The impact strength of the AA8050/ n-Si_3N_4 composites is evaluated through Charpy test as per ASTM E23. The impact specimens utilized have a V-notch 2 mm deep and radius 0.25 mm at 45°. Three independent tests were made, and the average of those values was used to calculate the final results.

2.3. Metallurgical properties (SEM, EDS, XRD)

In AA8050/ n-Si_3N_4 composites, distribution is essential in improving characteristics. The microstructural analyses aid in visualizing the distribution of strengthened n-Si_3N_4 particles in the AA8050 composites. For SEM analysis the process includes cutting the composites to the appropriate size, then grinding and polishing the surface. Paper of varying grits and diamond suspension on enhancing rags has been used to smooth the surface to mirror sheen and remove any remaining scratches. Disc polishing equipment was used to polish the entire sample mechanically. The Keller's etchant was used for etching the specimens cautiously to prevent over-etching [30]. EDS is utilized to assess the modifications to the material's microstructure. The chemical elemental makeup of the substance may be seen in the EDS image. Panalytical X-ray difractometer was used to characterize the AA8050/ n-Si_3N_4 composites in this investigation. Scanning speediness of 3°/m was used to acquire the XRD patterns. The scanning range (2 theta) for phase analysis of composite samples is 10° to 100°. Different peaks in the XRD data denote various elements and impurities, including aluminum, silicon, nitride and others.

3. RESULTS AND DISCUSSIONS

3.1. Physical characteristics

The physical characteristics including density and porosity of the synthesized specimens are obtained and are displayed in Figure 2. The addition of particles causes the theoretical density of AA8050/n-Si_3N_4 particles to increase, while the experimental density decreased slightly which may be due to the moisture content of the n-Si_3N_4 particles to evaporate, leaving a porous, low-density framework. Particle accumulation has caused B, C, and D densities to be slightly lower than experimental density. However, porosity may be primarily responsible for the discrepancy between the both densities. By matching the theoretical and experimental densities, porosity

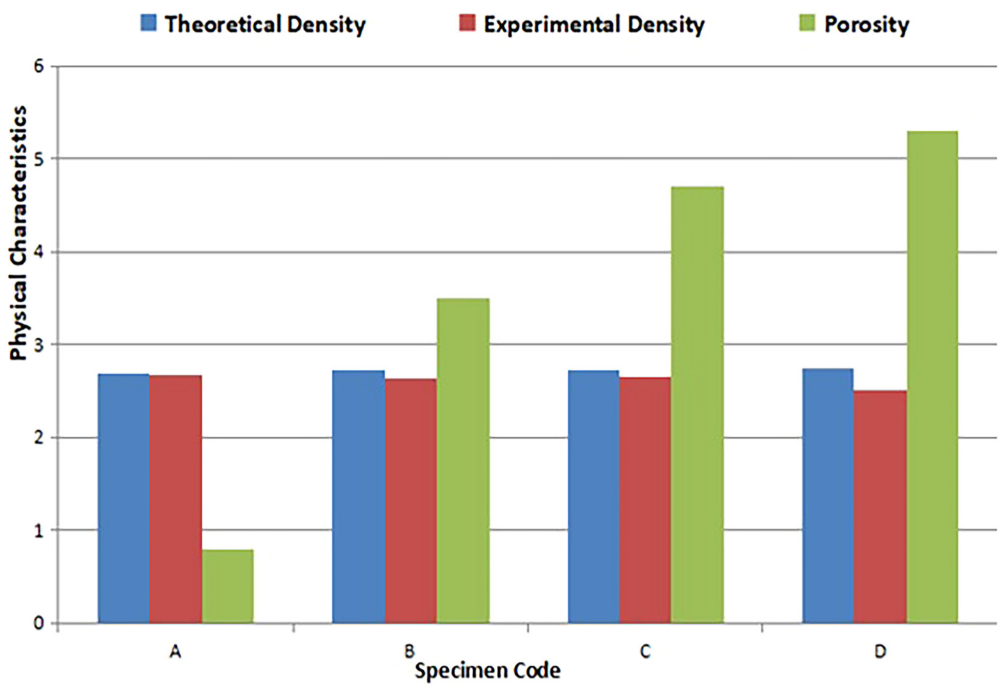

Figure 2: Density and porosity of fabricated AA8050/ n-Si_3N_4 composites.

is calculated accordingly. A 5.3% of porosity for specimen code D was obtained. When the reinforced particles agglomerate, they create a massive porosity in the composite, which degrades the material's qualities. When the porosity is decreased, the composite functions more effectively.

3.2. Mechanical characteristics

Specimen code (A) base alloy has UTS of 181 MPa. The results show that the addition of n-Si_3N_4 particles at different proportions raises the UTS from 181 MPa to 210 MPa. A material's flexibility can be measured by its ability to be stretched. Elongation decreases noticeably with rising UTS. Composites (B, C, D) have lower elongation compared to A, but they have higher UTS. Increased porosity in the matrix and the early formation of voids at minor strains in a tensile test may account for this drop in elongation. Figure 3 and Figure 4 shows the outcomes of the tensile and elongation results.

Specimen code (A) has an average microhardness of 62 HV. Adding n-Si_3N_4 particles has improved B, C, and D micro hardness over the as casted (A) alloy because reinforcement masks the dislocation movement. Microhardness measurements revealed that the C specimen (2.5% n-Si_3N_4) has the most

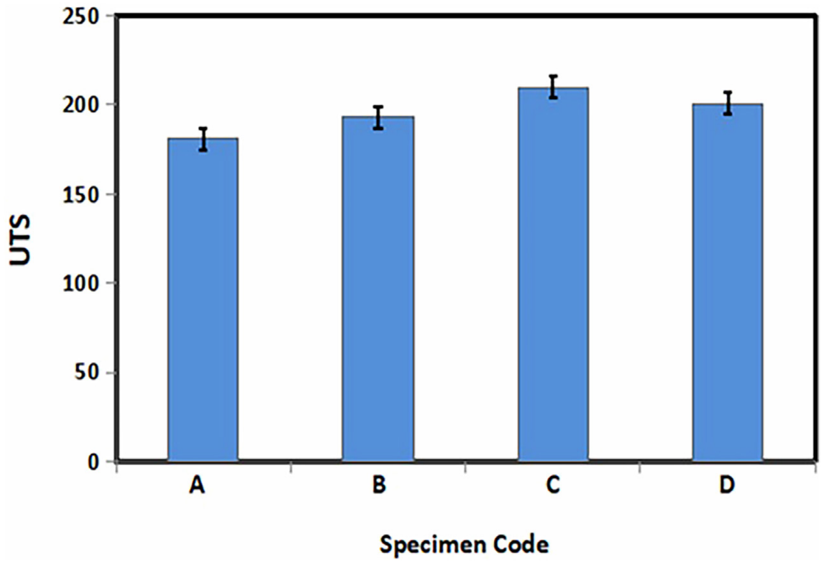

Figure 3: Outcome of UTS with AA8050/n-Si_3N_4.

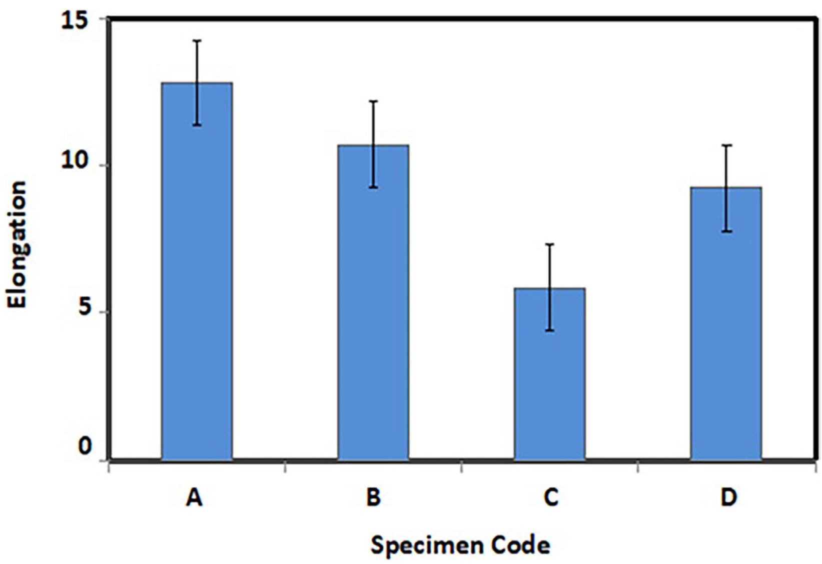

Figure 4: Outcome of Elongation test on with AA8050/n-Si_3N_4.

significant value (78 HV). There is a noticeable increase in Vickers hardness up to 2.5% reinforcement, but this trend reverses above that threshold. This might happen if the reinforcement coagulates at a more significant weight percentage, creating cavities. The outcomes are displayed in Figure 5.

The most significant value of 32.6 J was observed at a weight fraction of 1.5% n-Si_3N_4 particles added to the matrix AA8050, suggesting that this addition improves the IS. For values of percentage toughness of more than 1.5%, the energy required to overcome it begins to decline. One possible explanation is that the reinforced n-Si_3N_4 particles are so fragile. In addition, increased reinforcements may not significantly improve toughness due to the tendency of reinforcement particle segregation at sites. n-Si_3N_4 particles influence on impact was studied as seen in Figure 6.

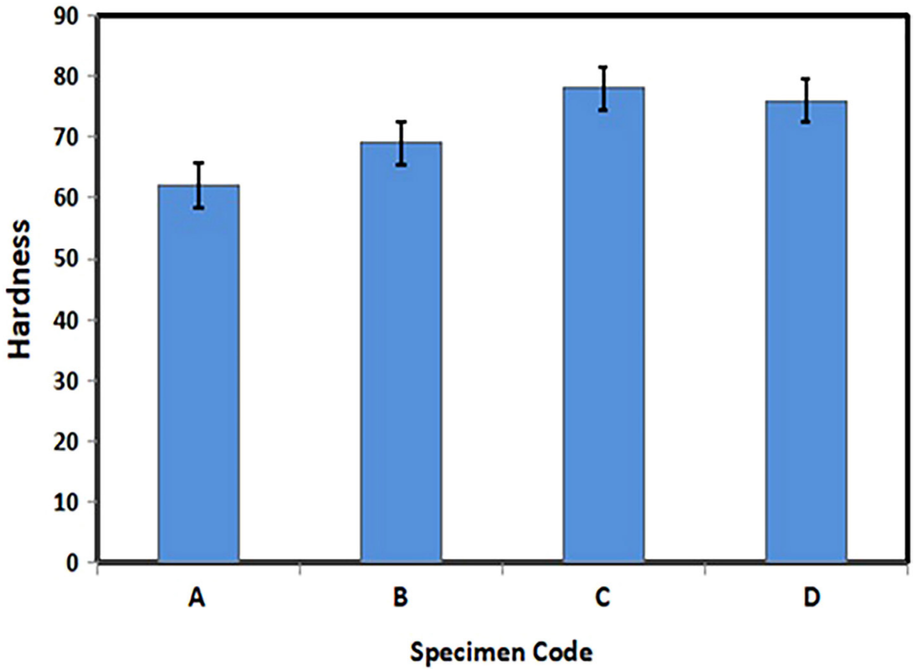

Figure 5: Evaluation of Micro-hardness with AA8050/n-Si_3N_4.

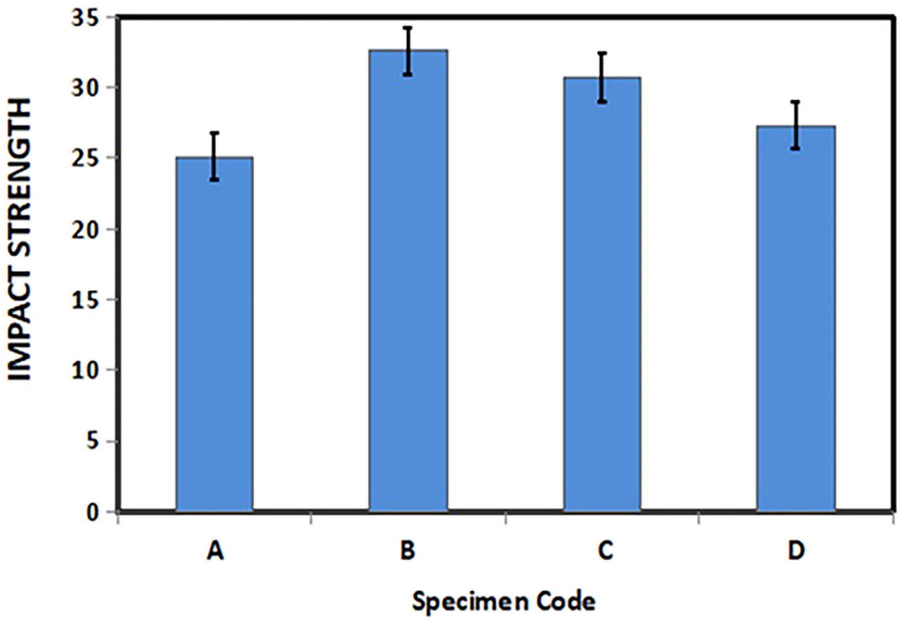

Figure 6: Evaluation of Impact strength with AA8050/n-Si_3N_4.

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3.3. Metallurgical characteristics

Specimen A has relatively broad grain boundaries compared to the other specimen (D). Dendrite development leads to the formation of grain boundaries. The weak wettability of n-Si_3N_4 particles by composites is overcome by the stirring force, preventing surface disruption. Because of this, the composite's microstructure is consistent throughout [31, 32]. According to the research, a typical Al-Si eutectic combination can be found in the AA8050 matrix. When the percentage of strengthened n-Si_3N_4 particles in the mixture rises above 2.5%, coagulation and cluster formation begin. Cluster formation occurs through the mixing and stirring steps. The melting point of the n-Si_3N_4 particles is quite high. Therefore, the AA8050 matrix has not undergone any chemical reaction. The SEM microstructure of 0% of n-Si_3N_4 was shown in Figure 7a and Figure 7b shows 3.5% of n-Si_3N_4.

All the manufactured AA8050/n-Si_3N_4 composites were put through an EDS analysis, and the findings are shown in Figure 8a-d. The spectra of the specimen show that the elements Al (the highest peak) as well as Carbon, Silicon, Magnesium, and Iron (the low elevation). The mold used to create the composites might be to blame for the presence of carbon. A higher concentration of Mg and Si can be found in composites than in most other elements. Magnesium, when added to the molten AA8050 during manufacture, promotes wettability among the reinforcement and lessens the propensity for accumulation. The EDS of the Specimen A is displayed in Figure 8a. As seen in Figure 8b and Figure 8c, neither Specimen B nor Specimen C exhibits an intermediate phase. Figure 8d shows that the percentage of n-Si_3N_4 particles is highest in specimen D. Just two elements, Al and Silicon, may be found in specimen A. n-Si_3N_4 particles exhibits a weaker intensity peak. In contrast, Al shows peaks that are much stronger in intensity throughout B, C, and D specimens. Figure 9 shows the XRD analysis of the AA8050/n-Si_3N_4. Nano silicon nitride particles are found to have the proportionally lowest peak in B and the most significant peak in D.

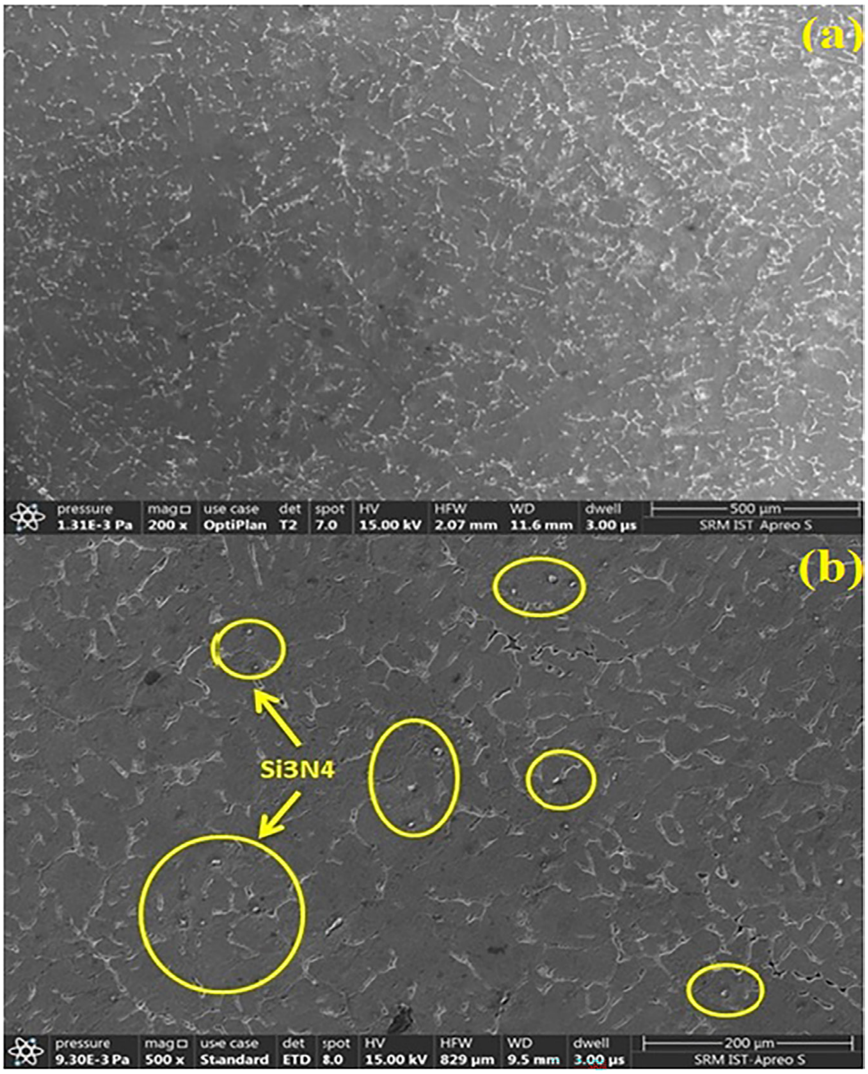

Figure 7: SEM images of (a) 0% n-Si_3N_4 (b) 3.5% n-Si_3N_4.

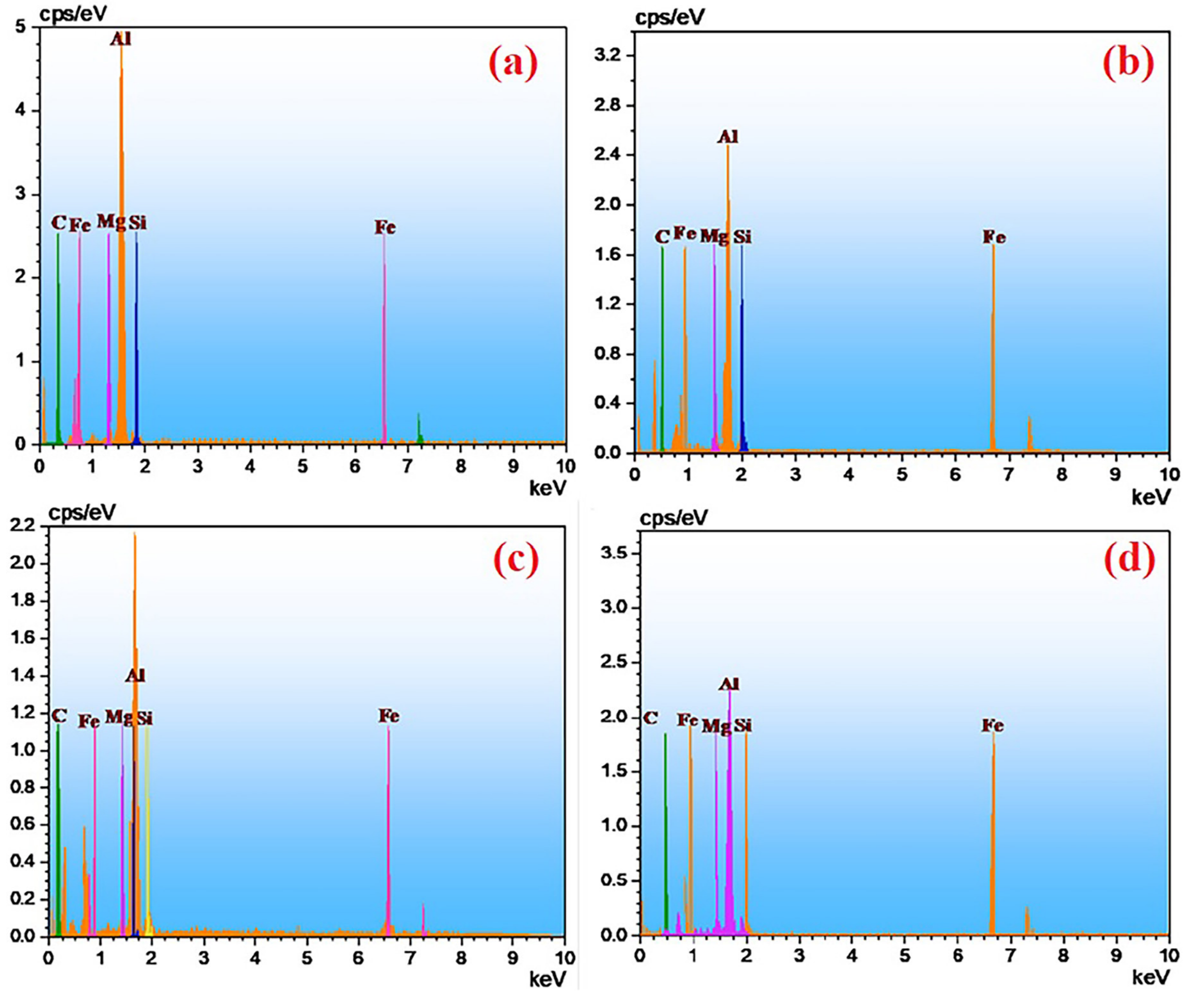

Figure 8: EDS spectrum of the AA8050/n-Si_3N_4 Composites (a) Specimen code A (b) Specimen code B (c) Specimen code C (d) Specimen code D.

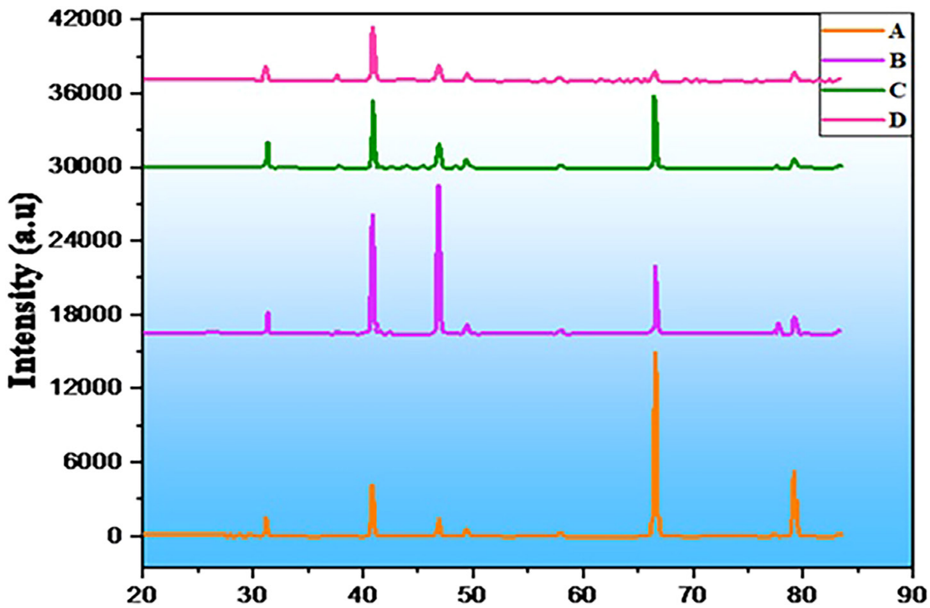

Figure 9: XRD analyses of the AA8050/n-Si_3N_4 composites.

4. CONCLUSIONS

Different reinforcement proportions of n-Si_3N_4 particles with AA8050 have been successfully achieved with a stir casting. Examining the impact of n-Si_3N_4 particles on physical, mechanical and metallurgical characteristics were done. According to the results of the research composites manufacturing is only appropriate up to a n-Si_3N_4 particles reinforcement weight fraction of 2.5%. From physical characteristics it is clear that as n-Si_3N_4 particles reinforcement increases, theoretical density increases while experimental density decreases. The theoretical density rise for 3.5% reinforcement is capped at 1.6%, while the observed density drop is capped at 3.1%. Composites porosity grows exponentially with increasing reinforcement fraction. At 3.5% reinforcement, the porosity is the maximum. From mechanical characteristics n-Si_3N_4 particles (up to 2.5 wt.%) introduced into the AA8050 typically result in increased UTS, Impact and microhardness. Higher percentage of improvement in properties is seen. Compared to the AA8050 matrix, the composites appear to have superior impact strength. Impact resistance is highest at 1.5% n-Si_3N_4. Outside of this composition, there is a declining tendency in impact toughness. The characteristics start degrading at around 3.5% by weight because coagulation of the reinforcement and poor interfacial bonding is responsible for the change. It has been shown that the ductility of the AA8050 matrix material decreases along with the percentage of n-Si_3N_4 particles, leading to a decrease in elongation. At 2.5% reinforcement, the least amount of elongation is achieved. Metallurgical characteristics clearly showed the evident of presence of silicon nitride nano particles and dispersion over the matrix AA8050.

5. ACKNOWLEDGMENTS

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