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Influence of TiO_2-Coconut Shell ash hybrid Reinforcement on Mechanical Performance of Al6061 Composites

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Abstract:

Present work investigates the mechanical properties of stir casted hybrid composites composed of different concentrations of TiO_2 and coconut shell ash in aluminium 6061 matrix. Four different compositions of composites were prepared by varying the weight percentage of Titanium dioxide (2, 4, and 6wt %) and the content of coconut shell ash was fixed at 3wt%. An evaluation of the tensile strength, hardness, percentage of elongation, and microstructure studies had been performed. The microstructure shows that both coconut shell ash and Titanium dioxide dispersed uniformly. With the inclusion of hybrid reinforcements, the ultimate tensile strength and hardness have been improved significantly. As the titanium dioxide increases in weight % in the matrix, causes the elongation to decrease. The tensile fractured surfaces were analysed using SEM to identify the strengthening and fracture mechanisms involved.

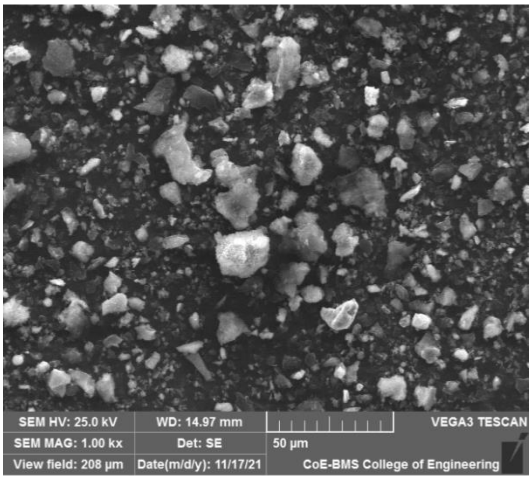
Keywords: Coconut shell ash, Titanium dioxide mechanical properties, hybrid composites, stir casting.

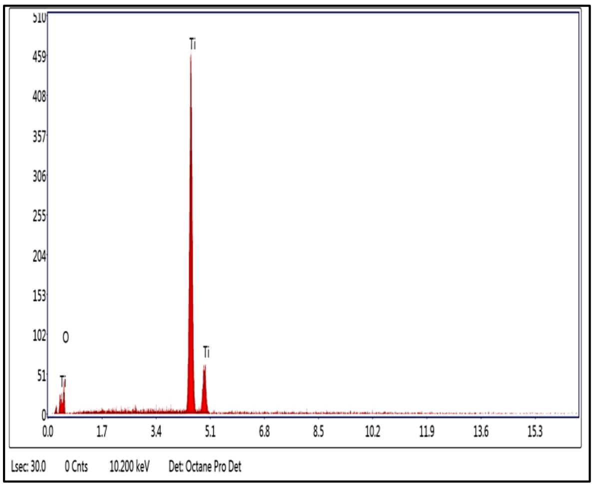
1.0 Introduction:

Even though unified metals and alloys frequently lack physical, mechanical, and chemical properties, aluminium matrix composites are classified as special materials. Aluminium matrix composites (AMCs) rank very high next to steel in a variety of technological domains. AMCs are now being used to design parts for leisure and sports, as well as vehicles, among other things. Low corrosion, high strength to weight ratio, rigidity, and high temperature tolerance are some of the properties that highlight their priority in aerospace and automotive applications. Because of the disadvantages of MMCs' high cost due to the high density of more commonly used ceramic reinforcements and interfacial reactions compared to aluminium alloys, researchers are interested in developing agricultural waste as an alternative reinforcement in composite fabrication [1-6]. When compared to traditional industrial ceramics reinforcement, a variety of agricultural wastes such as rice husk, bamboo leaf, and coconut shell, among others, can be regulated to produce energy-efficient, low-density ash with the lowest processing costs. Waste ash from agricultural operations could be used to create high-quality Al matrix composites, which could then be reinforced further with artificial one reinforcement. Because of the high concentration of silica and haematite in this agro-waste, it is an excellent reinforcement material. Coconut shell ash is primarily made up of silicon dioxide (SiO_2) and is readily and abundantly available [7-10].Investigation conducted by Prabu and lakshmi kanthan aimed to synthesize metal alloy, Al6061 - Coconut Shell Ash (CSA) and also determining their tribological and mechanical properties. It's been found that the composites which are reinforced with CSA of about 6% are least wearable; also the hardness and tensile strength were found maximum. The reasons for the increase in tensile strength, hardness and wear at with CSA in composites is that because of particles contribution to the dislocations when load is applied and also the presence of ceramic particles and metal oxides in the reinforcement[11]. The mechanical properties of a hybrid composites' based of Al metal matrix containing CSA, and B_4C of some quantity as reinforcement were studied by Sachin et al,[12]. In the study, several percentages of B_4C and coconut shell ash were used as reinforcement to assess the mechanical behaviour of aluminium metal matrix hybrid composites. In comparison with aluminum 6061, there was a slightly decreasing trend in hardness and a reduction in composite tensile strength [13].In another work [14] the authors have investigated the mechanical and flexural properties of Aluminium Matrix Composite made with the coconut shell reinforcement and as the matrix material Aluminium 6061. For the preparation of the AMC, stir casting has been chosen from the available options. For properties study such as hardness, torsion, impact, compression, a coconut shell particle of various volume % of filler was mixed with the matrix material and samples were prepared. The tensile strength and hardness of the reinforced substrate are increases when the weight percentage of reinforcement is increased. In a work carried out by Surabhi et al [15], the titanium dioxide reinforced to aluminium was prepared and its mechanical properties are studied. To conduct a comparative study, different percent of reinforcement were varied within the base metal matrix. The weight percent enhancement of TiO_2 reinforcements of 5%, 10%, and 15% resulted in an increase in density, hardness, impact strength, and ultimate tensile strength, while the TiO_2 reinforcement decreases compressive strength with increased concentration. The conclusion is that as the TiO_2 content increases, each of the properties increases due to the formation of strong bonds between the base matrix and reinforcement, as well as the reinforcement acting as a wettable component within the base matrix. Amithkumar et al. [16] have examined mechanical behaviour and microstructure of Al7075 alloy and studied the impact of graphite and TiO_2hybrid reinforcement. The technique of hot rolling and stir casting has been employed to fabricate the samples of Al6061 and its hybrid composites. According to a microstructural examination, the particles of reinforcement graphite and titanium dioxide are well dispersed, and they exhibit excellent adhesion to the Al7075 matrix alloy. The hybrid composites exhibited remarkably better tensile strength and micro-hardness than cast composites. Shivananda murthy et al [17] hybrid composites of AA7075 matrix based were made with fly ash and TiO_2 utilising the method of stir casting procedure and hot forging. The content of fly ash had been set at 3 wt% in hybrid composites, whereas the content of TiO_2 had been varied. In AA7075 matrix, the dispersion was found to be homogeneous of both reinforcements which was revealed by the images of SEM. Examination of hybrid composites under compression was conducted to determine their mechanical behaviour. Under compression, hybrid composites examinations presented an increase during the determining the mechanical behaviour. As multiple reinforcements were added, the strength of the composite increased, and it had been further enhanced with a higher percentage of particles TiO_2.According to a review of previous work, aluminium matrix composites are made from agro-based waste materials and industrial processes are extremely beneficial. Because of AMCs' excellent combination of material properties, low cost, ability to incorporate waste materials as reinforcement material, ease of processing, and other factors, many engineering applications call for the use of aluminium alloys as top choice materials. As an agricultural waste, coconut shell has several advantages over carbon and glass based ceramic reinforcements, including lower cost, high toughness, environmental friendliness, and increased decomposability, making it an excellent filler for composite materials as reinforcement. When used as a filler, coconut shell provides weather resistance, modulus, higher strength, and other benefits over unreinforced composites. By incorporating the filler coconut ash into aluminium, a low-cost value-added product will be created. The reinforcements of two or more in hybrid composites have a much greater degree of design flexibility than monolithic aluminium composites. Despite extensive research on composites, little is known about the mechanical properties of hybrid composites. As a result, a cost-effective hybrid composite containing coconut shell ash and TiO_2 reinforcements, as well as an Al6061 matrix material, was developed using the stir casting method. Coconut shell ash was chosen as one of the reinforcements due to its good physical properties and low density [18-20]. Coconut shell ash was significantly less expensive than other reinforcements. According to the literature, TiO_2 reinforcements can be used effectively for the development of hybrid composites due to their wear resistance, high hardness and strength, and low density.

2.0 Materials and Methods

As matrix material for the preparation of composites, Al6061 alloy was used (Composition: Mn: 0.55, Fe: 0.67, Mg: 0.92, Si: 0.76, Zn: 0.18, Cu: 0.32, Ti: 0.09, Cr: 0.23, Balance: Aluminium). Titanium dioxide which is commercially available was used as primary reinforcement, and coconut shell ash was used as secondary reinforcement. Coconut shell ash was synthesised internally following standard procedures described elsewhere [21-23]. The SEM and EDAX images of coconut ash and titanium dioxide particles used in this study are shown in Fig.1 (a-b).





(a)SEM and EDAX of TiO_2 particles

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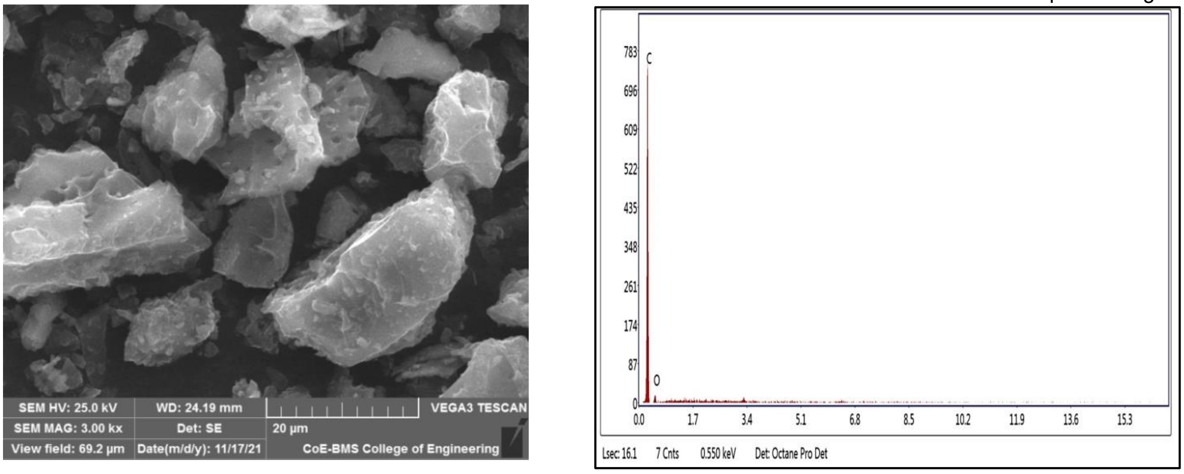

(b)SEM and EDAX of coconut shell particles

Fig.1 (a-b): SEM and EDAX of reinforced particles

The percentage of Titanium dioxide was varied in 2wt% increments up to 6wt%. For all composites, the percentage of coconut shell ash was set at 3wt%. For the preparation of composites, an electrical resistance furnace was used. 3 kg of Al6061 alloy was heated in a graphite crucible to 800 ºC. While stirring, titanium dioxide and CSA particles were added to the melt's vortex at a calculated percentage. The composite melt was stirred for 15 minutes with a stainless-steel impeller at 400 rpm. Following stirring, the molten mixer was degassed with hexachloro ethane tablets before being transferred to cast moulds for solidification. The same procedure is followed for pure Al6061 alloy as well as various percentages of titanium dioxide and coconut shell ash (CSA). Tensile tests, hardness tests, microstructure studies, and grain size analysis were performed on unreinforced Al6061 alloy and hybrid composite ingots. Tensile properties were evaluated as per ASTM A370 standard procedure. Fig.2 and Fig.3 presented below shows the tensile specimens dimensions adopted in the present investigation. Vickers hardness tester was used to measure the hardness values of hybrid composites and alloy. Average of 4 indentations was calculated to represent the hardness of composites. Average grain was determined using ASTM E112 method with the help image analysing software.

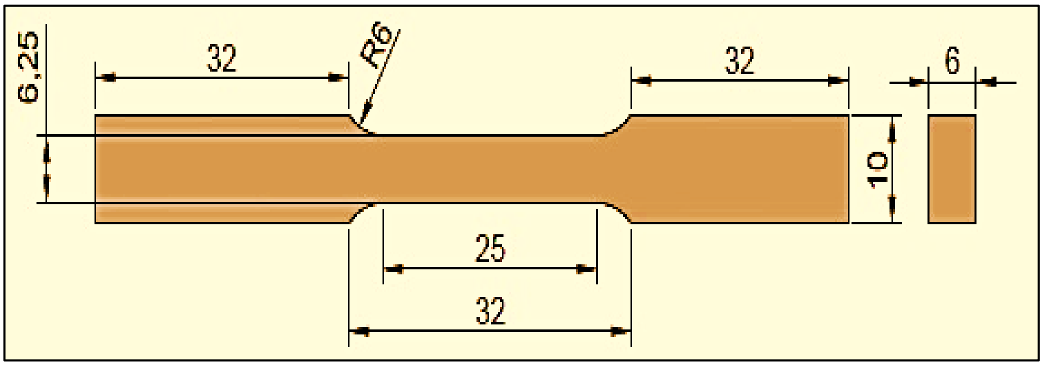

Fig.2: Dimensions of tensile samples in millimeter

Fig.3: Picture of Tensile test samples

3.0 Results and Discussions

3.1 Microstructure and X-ray diffraction analysis

The scanning electron micrographs of hybrid composites synthesized by stir casting method are presented in Fig.4. Although clusters of particles are seen in few areas, the dispersion of the coconut shell ash and titanium dioxide particles are objectively

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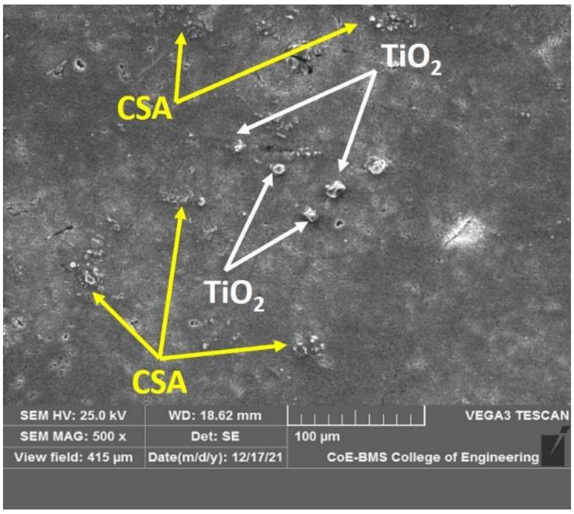
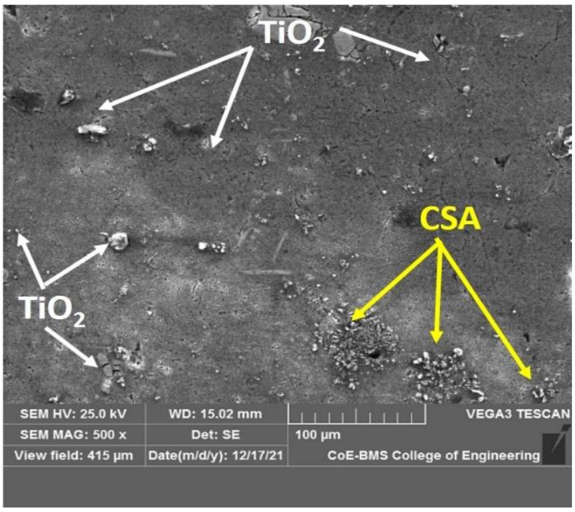
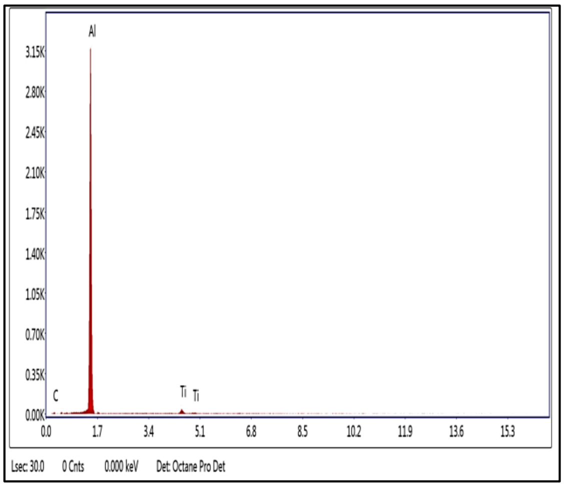
even. Further, there are no evident defects seen in any of the micrographs indicating good quality of the composites as a result of optimum processing condition espoused during processing. The microstructure captured at high magnification clearly depicts good association of the hybrid particles with matrix material. The elements seen in the EDAX reconfirms the presence of coconut shell ash and Titanium di oxide particles.

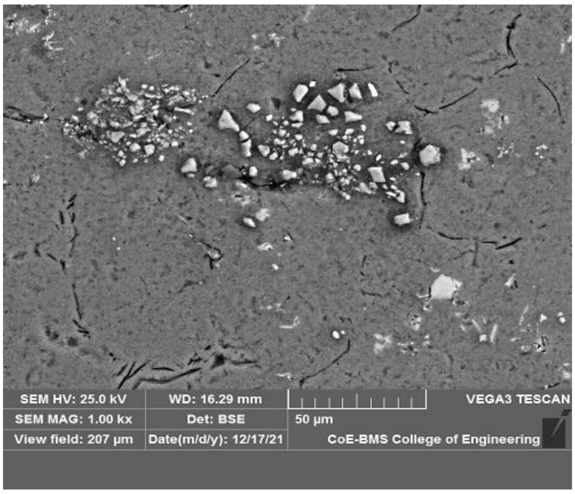


(a) Al6061+3wt%CSA+2wt%TiO_2



(b) Al6061+3wt%CSA+4wt%TiO_2





(C) Al6061+3wt%CSA+6wt%TiO_2

Fig.4: Scanning Electron Micrographs of coconut shell ash and TiO_2 reinforced Al6061 hybrid composites with EDAX image.

The x-ray diffraction pattern of Al6061-6wt% TiO_2-3wt% coconut shell ash composite is shown in Fig.5. It is also clear that the as xrd pattern does not exhibit any undesirable phase developed hybrid composite is free of interfacial reactions as a result of controlled processing temperature and mixing time. The presence of coconut shell ash particles and Titanium dioxide is confirmed by x-ray diffraction analysis.

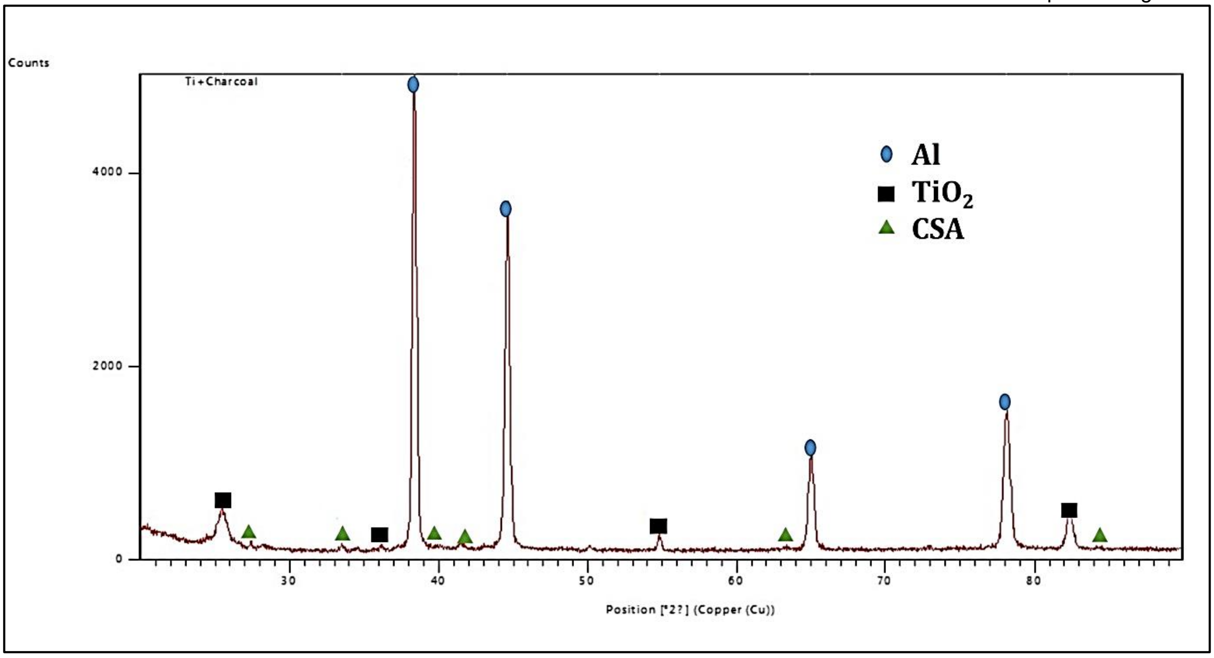


Fig.5: XRD of hybrid composite (Al6061+3wt%CSA+6wt%TiO_2)

3.2 Grain Size and Hardness

Fig.6 depicts the grain size and hardness of Al6061 and its hybrid composites with varying TiO_2 particle weight fractions. It can be seen that the grain decreases with the addition of both reinforcements. Furthermore, as the weight percentage of TiO_2 particles increases, the grain size decreases even more. The reduction in grain size from 63 microns for Al6061 alloy to 46 microns for hybrid composite with 3wt% coconut shell ash and 6 wt% TiO_2 was attributed primarily to the presence of two reinforcements as well as hot forging. To begin, both coconut shell ash and TiO_2 can contribute to the processing of composites in a variety of ways. The first is by accelerating recrystallization, and the second is by retarding grain growth. In general, aluminium or aluminium alloys do not exhibit dynamic recrystallization, but in the presence of second phase particles, they do. Both the micron size reinforcement's coconut shell ash and TiO_2 can aid in the nucleation of new Al6061 grains in this case. During deformation, the coconut shell ash and TiO_2 particles pin the grain boundaries of the Al6061 matrix in the second case. This is an intriguing phenomenon because these particles serve as nucleating sites for new grains while also limiting recrystallization. However, it should be noted that the Al6061 grain experiences two types of pressures during casting: driving pressure for grain growth and pinning pressure due to the presence of reinforcements. In the case of composites with reinforcements, the Zener pinning pressure is greater than the driving pressure for Al6061 grain growth. This claim is well supported by grain size values, as grain sizes in composites are smaller than those in Al6061 alloy.

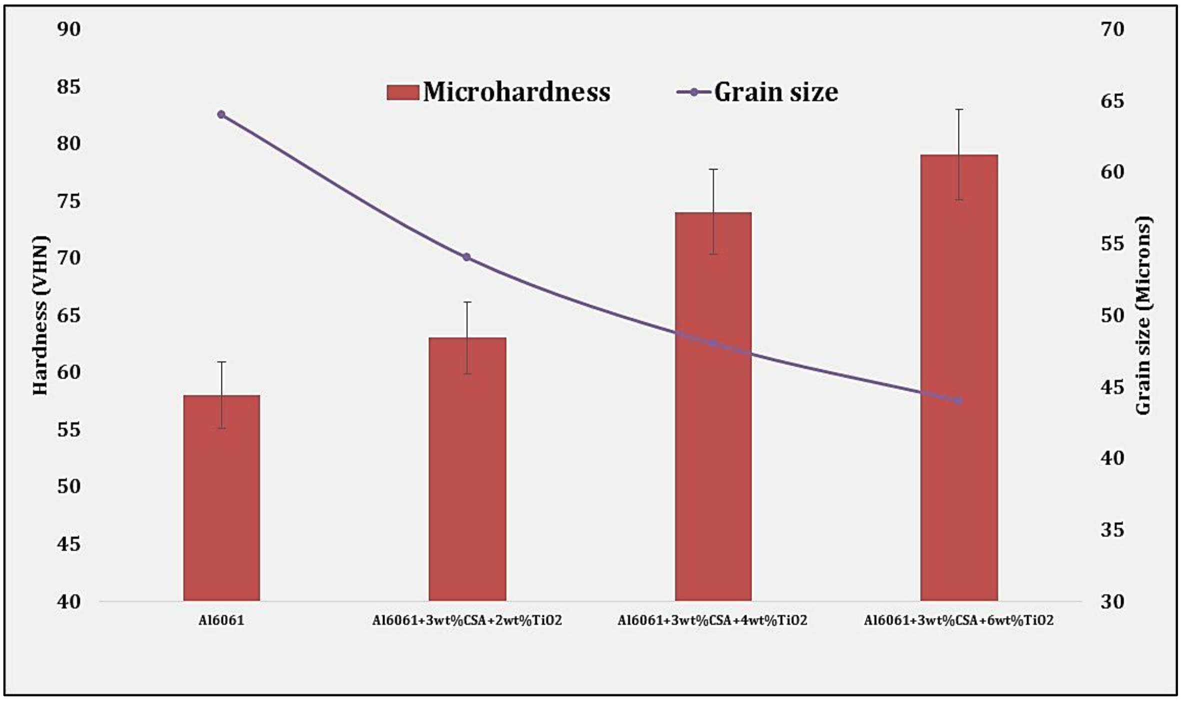


Fig.6: Graphical representation of hardness and grain size variation in hybrid composites

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Figure 6 clearly shows that adding reinforcement particles increases the hardness of the composite. Based on the composition of the CSA particles, it is easy to deduce that SiO, a very hard ceramic particle in its own right, makes up a large portion of them. Because of the presence of hardening components such as MnO, MgO, and SiO_2 in reinforced ash, the hardness of Al metal should increase when these CSA particles are used as reinforcement material; additionally, we can see particles are dispersed uniformly in the aluminium matrix. Silicon oxide particles take up the load that is uniformly distributed throughout the matrix. Al was found to have a hardness of 57.5 HV, and when compared to samples reinforced with 3% CSA+6%TiO_2, there is a 32 percent increase in hardness value for Al when compared to samples reinforced with hybrid particles. This essentially means that as the unreinforced matrix is coupled with hard reinforcement, it undergoes a positive transformation in terms of properties. In this way, strengthening a pure aluminium base matrix with CSA and TiO_2 increases the hardness of the base matrix material. When the coconut shell ash was mixed with TiO_2, the hardness increased with increasing weight fraction. Titanium oxide and coconut shell ash particles were discovered to have a higher hardness than aluminium. This is due to the hardness and higher density of titanium oxide particles, which, as previously stated, are found in coconut shell ash particles. As a result, the composite is harder than pure aluminium. Because the Titanium oxide particles in this composite are strong, it can withstand the load applied to it. The load acting on the specimen will be nullified due to the particles' higher hardness and density.

The hardness of hybrid composites is higher than that of Al6061 alloy due to the following factors [24-26].

1. The hardness of reinforcing phases is higher. The addition of hard reinforcements such as TiO_2 and CSA to the soft ductile matrix increases the hardness of the composites.

2. Because the coefficients of thermal expansion of the Al6061 alloy and reinforcing phase are so different, the density of dislocations increases, creating a barrier to plastic deformation.

3. Composite hardness has been significantly increased due to extensive grain refinement, uniform reinforcement phase distribution, and improved interaction between reinforcement particles and matrix.

3.3 Tensile Properties

The addition of coconut shell ash and TiO_2 particles to the aluminium matrix results in a significant increase in the tensile strength of the composites. Fig.7 shows how the strength of composite increases with the addition of reinforcing particles due to its material composition.

Specific oxide particles exist in the ash that has been blended with the aluminium matrix and bind to the matrix material, such as silicon oxide, magnesium oxide, manganese oxide, and aluminium oxide. Tensile testing entails applying forces to the specimen that transfer from the matrix to the reinforcing particles. These reinforcement particles had helped the matrix material withstand deformation until it reached the yield point. Though the reinforced particles can bear a significant amount of load during loading, they are still ceramic particles, which means that the composites may not show any necking after yielding and will fail suddenly.

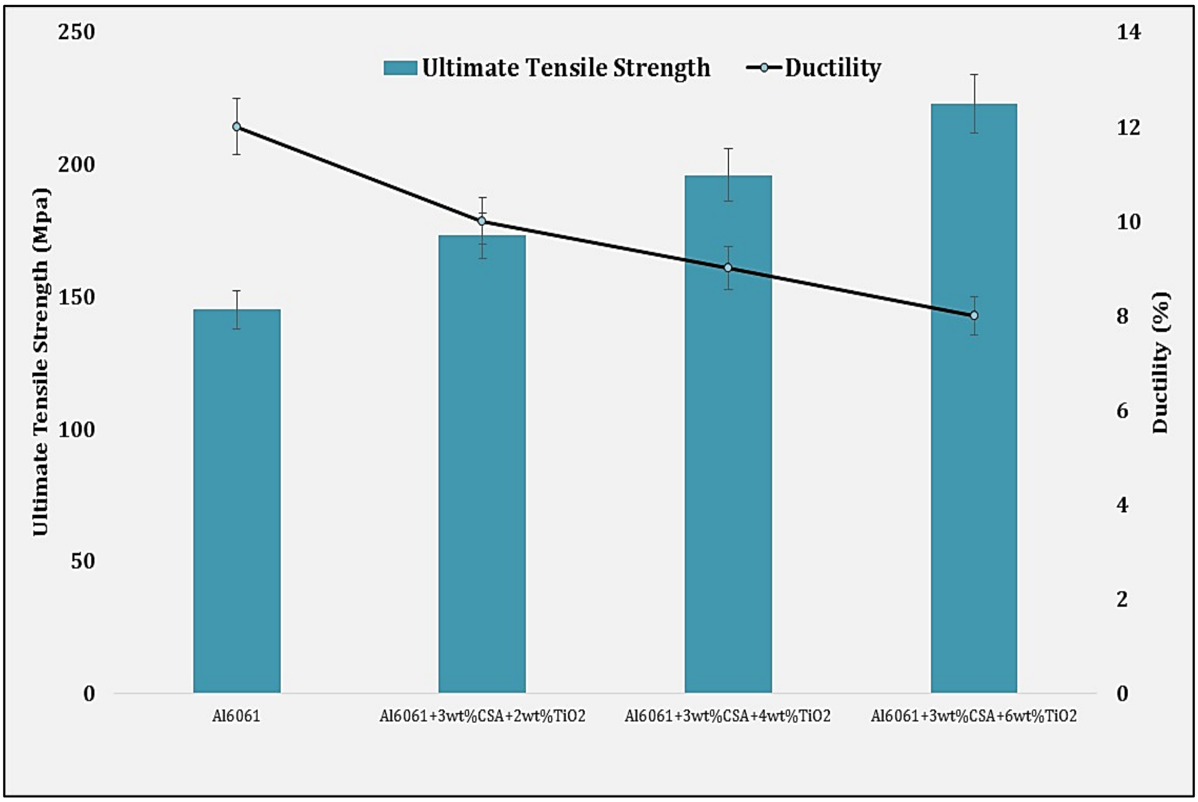

Fig.7: Graphical representation of ultimate tensile strength and ductility in hybrid composites

Because they bear and absorb loads, ceramic $TiO_2$and coconut shell ash particles are known to be load bearing and load taking elements in composites. This is confirmed by hardness tests. Because of their inherent properties, $TiO_2$and coconut shell ash

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particles are hard and brittle. It is critical that these materials be reinforced over a softer matrix material, as this will result in significant property improvements.$TiO_2$and coconut shell ash particles allow the matrix to behave as an isotropic material by obstructing dislocation movement during plastic deformation. As a result, the tensile strength of the composite is increased.

Several mechanisms contribute to the overall increase in the strength of hybrid composites. The potential mechanisms for the current hybrid composites are discussed in this paper. The grain size of Al6061 alloy can be controlled by using second phase particles as reinforcements in this case. These reinforcements are capable of controlling the grain size of the Al6061 alloy via particle stimulated nucleation. As a result, each small grain can aid in the nucleation of recrystallized grains during casting. These particles not only aid in the nucleation of new grains, but also in pinning subgrains and preventing them from growing into larger grains.

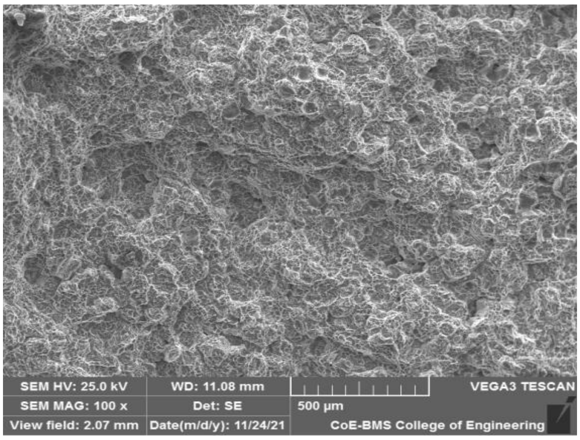
Because of the large CTE difference between both reinforcements and Al6061, thermal mismatch strengthening is another possible mechanism that contributes to strengthening and results in dislocation formation. Because of the significant differences in thermal expansion coefficients, the thermal mismatch stress in the current hybrid system of Al6061-coconut shell ash-TiO_2 is found to be very high. This thermal stress causes dislocations in the vicinity of reinforcements and within the matrix. This significant mismatch causes prismatic punching of geometrically necessary dislocations near coconut shell ash and TiO_2 particles, resulting in work hardening of the Al6061 matrix. Higher work hardening can be expected with the uniform distribution of both reinforcements. This allows for a greater increase in the strength of hybrid composites. Furthermore, the orowan strengthening mechanism plays an important role in preventing dislocation movement via reinforcements. The presence of finer-grained reinforcement can act as an impediment to dislocation movement. The main point is that these ceramic reinforcements are so tough that dislocations cannot deform or cut through them. Dislocations will overcome the resisting force and bypass the precipitates or fine reinforcements in order to accommodate the increasing internal stress. During bypass, or when dislocations are able to move in between the precipitates or reinforcement, they leave a loop around them known as the orowan loop.

The ductility of Al6061 alloy and its hybrid composites with varying TiO_2 content and coconut shell ash is shown in Fig. In addition to increasing TiO_2 content, ductility is decreasing. The Al6061 alloy had the highest ductility, while the Al6061-3 percent coconut shell ash-6 percent TiO_2 hybrid composite had the lowest. When Al6061-3 percent coconut shell ash -10 percent TiO_2 hybrid composite was compared to other hybrid composites with 2, 4, and 6 wt percent TiO_2 content, the maximum drop in ductility of about 58 percent was observed.

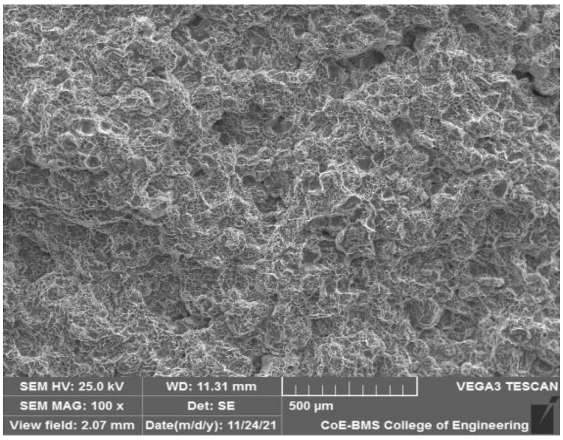
The decrease in ductility was primarily attributed to the presence of irregularly shaped reinforcement, particularly TiO_2, whose sharp edges act as crack nucleation sites. The presence of hard ceramics causes embrittlement due to local stress concentration at the matrix-reinforcement interface. Another factor that may contribute to low ductility values is particle cracking. Many other studies on composites have found that adding hard ceramic phases to a soft ductile matrix reduces ductility in base metals and alloys [27-32].

3.4 Fractography

A thorough understanding of the fracture mechanism of Al6061 alloy and hybrid composites is required to correlate microstructure and tensile properties. The failure of the Al6061 alloy, as illustrated in Fig.8, is quite ductile in nature.



(a) Al6061 alloy



(b) Al6061 alloy

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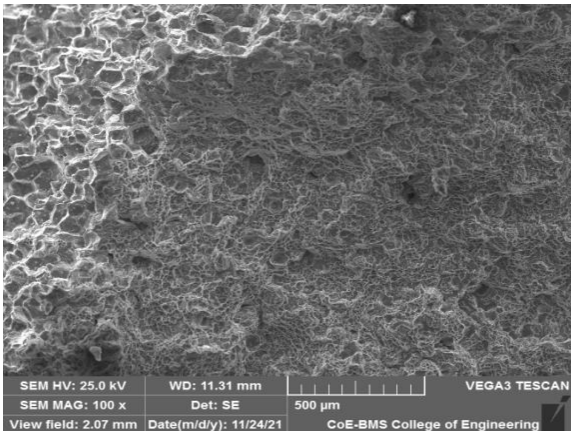
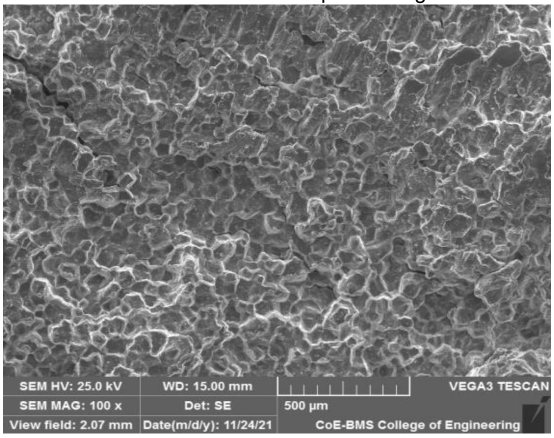
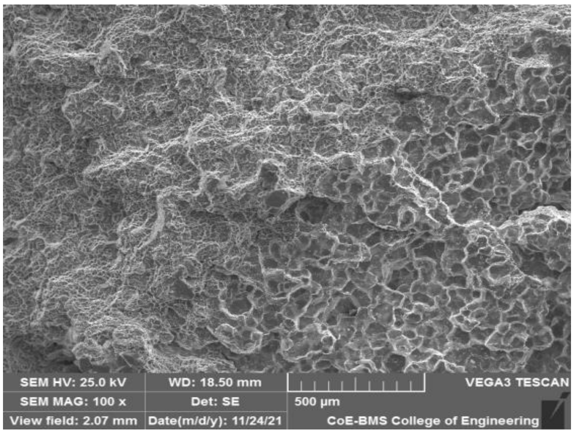


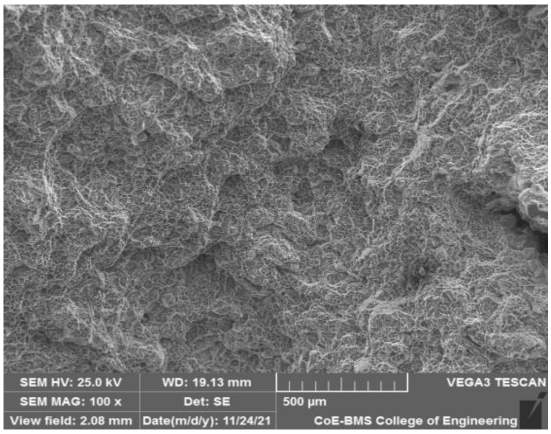
(c) Al6061+3wt%CSA+2wt%TiO_2



(d) Al6061+3wt%CSA+4wt%TiO_2



(e) Al6061+3wt%CSA+6wt%TiO_2



(f) Al6061+3wt%CSA+6wt%TiO_2

Fig.8 (a-f): SEM of Tensile fractured surfaces

The presence of voids and their growth indicates that the alloy underwent significant plastic deformation prior to final fracture. Under close inspection, the AA6061 alloy case reveals a typical ductile failure in terms of tear ridges and dimples. Furthermore, alloy has wider and deeper dimples than hybrid composites, which explains why alloy is more ductile.

The cracks formed at the matrix-reinforcement interface are primarily responsible for composite failure, which results in reinforcement debonding or cracking. The SEM image in Fig. 8 b of a hybrid composite containing two weight percent TiO_2 shows macroscopically brittle failure, but closer inspection reveals ductile fracture. A closer examination of the micrograph reveals the presence of ductile fractures in smaller voids. The failure is brittle in hybrid composites with the highest TiO_2 (6wt percent) content, as seen in the SEM micrograph (See Fig. 8 c). Because there are no plastic deformation features such as dimples, this composite fails due to brittle rupture. In addition, particle debonding has been observed in a few locations. The debonding of TiO_2 particles is caused primarily by high localised stresses around the particles as flow stress increases. As a result of the high stress, and this stress prior to the pre-crack, voids form between the damaged TiO_2 particles, resulting in brittle failure. Brittle failure of hybrid composites with the highest TiO_2 content is thus caused by a lack of plastic deformation and particle debonding.

4.0 Conclusions

Based on the above study, the following conclusions were reached:

a. As reinforcement elements, Coconut Shell Ash and TiO_2 particles have been successfully used in stir casting technique to prepare composites made with Aluminium 6061 as the matrix material.

b. Average grain size reduces with presence of Coconut Shell ash/TiO_2 content in the matrix, when compared with unreinforced alloy. An extensive grain refinement is observed in the hybrid composites.

c. The hardness of the composite increases as the Coconut Shell ash and TiO_2 concentrations are increased in the blend. By introducing the particles of TiO_2 as reinforcement, the composites will also be harder because the particles in the samples functions as the elements of load bearing.

d. TiO_2 as well as Coconut Shell Ash increased the ultimate tensile strength of the composites. However, the elongation coefficients were improved significantly when the particles of TiO_2 used as reinforcement since the particles of hard ceramic seem to restrict the composites elongation when loaded.

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