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Mechanical and Micro Structural Properties of Aluminum Metal Matrix Composites (MMC) Reinforced with Coconut Shell Ash Particulates and Graphene

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Abstract

This research article mainly focused on the fabrication of aluminum metal matrix composite reinforced with coconut shell ash particulates and graphene to enhance the mechanical and micro structural behaviour. The coconut shell ash particulates (CSA) and graphene are reinforced with 6061 aluminum alloy. The fabrication of aluminum metal matrix composites were prepared by adding various weight percentages of graphene and coconut shell ash particulates in aluminum alloy by using stir casting techniques with a restricted environment. The proper reinforcement on 6061 aluminum alloy materials play a very important role in enhancing its mechanical and micro structural properties. The results obtained reveal that the mechanical properties were improved by increasing the percentage on graphene and coconut shell ash particulates such properties are tensile strength, hardness and yield strength of 6061 aluminum alloy materials. The micro structural analysis reveals that the proper dispersion of graphene and coconut shell ash particulates in 6061 aluminum alloy materials. The enhanced mechanical properties were obtained by addition of 8wt% of coconut shell ash particulates and 0.8wt% of graphene.

Keywords: *Aluminum Metal Matrix Composites, Stir casting Method, Coconut Shell Ash Particulates, Graphene and Micro structures*

1.0 Introduction

The metal matrix composites are obtained by reinforcing metals with any other metals, ceramics or any other organic compounds. Basically the idea behind the reinforcements is to improve the properties of the base metal in all the aspects (strength, fracture toughness, wear resistance etc). When we say MMC the aluminum and its alloy has drawn major attention due to their already available best properties[1]. The application benefits of Al and its alloy includes major sectors like automobile, aircraft and even space etc[2]. When reinforcements are considered, they should have stability and non-reactivity under the given temperatures. Silicon carbide, boron, silica are the majorly considered reinforcements as they inhibit properties like tensile strength, high hardness, resistance to wear into the aluminum and its alloys[3]. The extensive sharing promotes good distribution of particles which is responsible for improvement in properties. When

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the different reinforcements are considered, boron carbide is one such addition which increases Young's modulus and fracture toughness but fails in improving the resistance to wear characteristics[4]. For the increase of wear resistance zircon is one such hybrid addition which is used in the fibre form[5]. In thermal plants, the waste by products such as dry ash is easily available and economical with good individual properties (electrical). Hence, the use of fly ash as reinforcement to the aluminum base is being increased. As said earlier, due to major beneficial applications of aluminum and its alloys reinforced with other components, this paper tries to explain (1) effect of different reinforcements (2) mechanical properties (3) fabrication methods (4) application benefits.

2.0 Literature Review

2.1. Aluminum Alloy Reinforced with Al_2O_3

Abhishek Kumar et al [6], considered A359 as base metal and Al_2O_3 as the reinforcements with varying wt% of 2, 4, 6, 8%. The composite was fabricated using stir casting method (electromagnetic) and at a temperature of 750ºC the melting was carried out. The samples were prepared for mechanical tests and the tests were conducted as per standards. The test results were tabulated and discussed. It is clearly shown that with the increase in wt% of Al_2O_3 the hardness of the composite increases gradually. Also the UTS of the composite is increased with an increase in the wt fraction of Al_2O_3. Micro structural study reveals that the electromagnetic stirring facilitates good bonding between matrix and reinforcements and shows finer grain size in the cast.

Mohsen Hossein-Zadeh et al[7], has worked on investigating the effect of heat treated Al_2O_3 reinforced into A356 base. The composite was prepared using stir casting technique. Micro structural and mechanical characterization was carried out to study the effects of heat treated Al_2O_3 with higher and lower grain size. Micro structural analysys show increase in the active surface and also a new structure which may be due to grooving. Also there is an evidence of less agglomeration in MMC with heat treated Al_2O_3 as compared to Al_2O_3 which is non-heat treated. Hardness and compression test showed improvement results as compared to non-heat treated Al_2O_3. Wear resistance is also seen to be improved while in the case of MMC made with heat treated reinforcement.

Bhaskar Chandra Kandpal et al[8], studied the characterization of Al6061 reinforced with Al_2O_3. The fabrication of MMC was done using stir casting method. 5, 10, 15 and 20 wt% of reinforcements were used and the specimens were prepared for characterization. Micro structural characterization shows grain refinement due to the use of Al_2O_3 and good bonding between the matrix and reinforcement. The hardness study shows considerable increase in the property but the tensile test results show only marginal improvement in the tensile strength which may be due to the inefficient stirring while fabrication. Also loss of ductility is seen with the increase in reinforcement which may be due to increase in Al_2O_3.

Chennakesava Reddy[9], fabricated Al6061, Al6063 and Al7075 with Al_2O_3 reinforcements with 12, 15 and 20% using stir casting technique. Mechanical characterization was done and it is clearly shown that the ductility is decreased with the increase in reinforcement percentage and also it was observed that the difference between UTS and yield strength was only marginal which was attributed to the decrease in work hardening post yield point. Intermetallic compounds were also formed. Also it is shown that the particle size determines the increase or decrease in the properties. Fine particulate facilitates increase in the properties. Agglomeration is more found as the percentage of reinforcement is increased.

2.2. Aluminum Alloy Reinforced with SiC

Md. Habibur Rahman et al[10], fabricated Al reinforced with SiC (5, 10, 15 and 20%) and did mechanical, wear and microstructure characterization. The test results show that the MMC with 20% reinforcement shows increased hardness, UTS and wear results. Micro structural analysis shows uneven distribution of SiC and clustering as the reinforcement is increased by weight. Porosity was also found to be increased with the increase in reinforcement.

Rajesh Kumar Bhushan et al[11], fabricated and characterized the Al-7075 and SiCp (10, 15, 20 and 25%) using stir casting method. The micro structural study shows the alloying and segregation of Al and Mg which results in restricting the formation of Al_2C_3 at the interface. The oxidation prevents chemical reactions. A little addition of Mg facilitated the wetting between matrix and reinforcement. Also SEM results show reinforcements uniformly distributed along the matrix and no other chemical reaction is visible. The overall analysis shows that the developed composite may be used in environment with temperatures less than 1250ºC and are applicable in all the major sectors.

J Yang et al[12], studied the production and characterization of Al/SiC particulates with high volume fraction. The study showed very clearly that size of the particles play a major role in property variation. The variation is related to the amount of damage caused by the reinforcement size. It is seen that the particles tend to crack which increases with the increase in the particle size. Majorly the strength of flow of the matrix is affected due to the cracking and also the crack severity influences inversely the ductility and strength of the MMC.

S Valdez et al[13], synthesized and characterized the Al-Mg-alloy/SiC particles MMC using vortex method of fabrication. With micro structural analysis it was seen that there were no chemical reactions due to which the mechanical properties will be affected in a good manner. Uniform distributions of particles were observed and no Al_2O_3 oxide film layer was not observed. This proved the utilization of vortex method for generating good quality homogeneous MMC involving Al/SiC.

2.3. Aluminum Alloy Reinforced with B4C

N. Rajesh Jesudoss Hynes et al[14], developed and analyzed AA6061 alloy reinforced with B4C particulates fabricated using stir casting technique. The percentages of reinforcements taken were 5, 10 and 15. The increase in the reinforcement volume yielded better mechanical properties and it was shown that the tensile strength and hardness were improved. The wear resistance property of the developed MMC was observed to be enhanced at 15% of reinforcement which leads the composite to be used in important applications including in the fields of automotive, aerospace and nuclear engineering.

M. Mohan et al[15], developed Al/B4C/Gr MMC with wt% reaching to 10% both combined using stir casting technique. It was observed from the mechanical characterization that the MMC with 5% B4C+5% Gr showed better tensile strength and hardness whereas the composite with 5% B4C+2.5% Gr showed better results in the impact strength. The combination of reinforcement and matrix with the defined values is suitable for high grade applications.

B Manjunatha et al[16], prepared MMC with Al6061 and B4C particles using liquid metallurgy route with reinforcement percentage of 2, 4 and 6. Micro structural investigation showed uniform distribution of B4C particles in the matrix. While the tests were conducted it is shown that the UTS, hardness and wear resistance was increased with the increase in the B4C particulates. The wear parameters governing the wear of the specimen were optimized using response surface methodology and the SEM analysis of wear surface depicts clearly that the wear behaviour is dependent on the percentage of reinforcements added. Increase in the wt% of reinforcements increase wear resistance.

Santhosh T U et al[17], investigated Al6061/B4C MMCs fabricated using stir casting technique. It is seen that the mechanical properties and the wear rate are the functions of wt% of reinforcements. The hardness and tensile strength of the composites were increased with the increase in wt% of B4C and wear rate was found to be decreased with the increase in B4C particles.

2.4. Aluminum Alloy Reinforced with Fly Ash

H C Anil Kumar et al[18], investigated the effect of various percentage and particle size of fly ash on Al6061 alloy by considering different sizes of fly ash particles with 10, 15 and 20% of reinforcement in the matrix. Different sizes were 5-25, 40-50 and 75-100 μm. The tensile and hardness results showed increase in the UTS and hardness values with the increase in fly ash percentage of 5-25 μm size but there was a clear indication of decrease in these values when the particle size was increased. Micro structural analysis showed good uniform distribution of reinforcements in the matrix which proves the worthiness of stir casting technique.

Charles Edrard et al[19] used Al6061 and selected graphite and fly ash as the reinforcement material for the study. The variation in reinforcements was considered to be 0,4,6,8 wt.%. The liquid metallurgy route was used for composite preparation. Mechanical characterization showed that with the increase of graphite and fly ash, tensile strength of the composite increased. Due to the excess porosity, theoretical densities were more than the experimental density. Values of densities of Al6061 with fly ash are found to be more superior to Al6061 with Gr.

Milind K Vasekar et al[20] prepared MMC of Al6061-fly ash and compared it with another prepared MMC of Al6061- fly ash/SiC and Al6061-fly ash/MoS_2 hybrid MMC using different weight fractions of reinforcements and stir casting method. Micro structural and mechanical experiments were done. It is seen that with the addition of SiC and MoS_2 particulates into the Al6061-fly ash composites, increase in hardness in tensile values were seen. Comparatively, the values were higher for Al6061-fly ash/SiC composites than the other two. Hence for critical applications like disc brakes in automobile Al6061-fly ash/SiC can be used. Further, wear characteristics of the prescribed composites must be analyzed.

S Balakumar et al[21] focused using fly ash, graphite and copper in Al6061 matrix through stir casting technique. Taguchi method has been used to optimize composition percentage in the MMC. Wear and friction characteristics were determined in the results. It has been clearly discussed that the hardness of the composite has been increased with the increase in addition fly ash and graphite. With the used reinforcements, both wear rate and friction forces were seen to be decreased.

2.5. Aluminum Alloy Reinforced with Coconut Shell Ash

K Varalakshmi et al[22] reinforced Al6061 with coconut shell ash with a ranging percentage of 1, 3 and 5 using stir casting technique. The authors conducted density, porosity, hardness, tensile and wear tests and found decrease in density and porosity whereas increase in hardness and tensile strength values. Micro structural study showcased good bonding between the reinforcements and base and also uniform distribution of the reinforcements.

P Lakshmikanthan et al[23] studied the mechanical and tribological characteristics of Al6061-CSA developed by stir casting pallet method. The weight percentages of reinforcements chosen are 3, 6, 9, 12, 15%. Mechanical characterization showed that there is an initial increase in the properties as the reinforcement particles acts as barriers towards dislocations at the time of application of load and also due to the presence of oxides of metals and particles of ceramics in the reinforcements. Wear rates were also noticed to be decreased. Friction force and friction coefficients were seen to be increased and that may be due to the debris formed during wear. SEM evaluation emphasis on the use of stir casting pallet method efficiently in fabricating MMCs.

KolusuVaralakshmi et al[24] analyzed the dry sliding wear behaviour of Al6061-CSA MMC fabricated using stir casting method. Weight percentages of reinforcements were taken as 0-6%. The results showed decreasing trend in density and increasing trend in hardness and tensile strength whereas, the wear rate was observed to be decreased with the addition of CSA particles. SEM and EDS investigations proved stir casting method as efficient due to the uniform distribution of reinforcements.

2.6. Aluminum Alloy Reinforced with Graphite/Grapheme

I Manivandan et al[25] studied the mechanical and tribological behaviour of Al6061-SiC/Gr self-lubricating hybrid nano composites developed through stir casting technique. It was observed that hardness of SiC and Gr prevents dislocations due to which mechanical properties were enhanced. Al/1.2SiC/0.5Gr exhibit good tribological properties at all the loads applied and reach maximum friction coefficient of 0.23. Reinforced composites exhibit grooves and pits of certain depth as compared to basic aluminum metal. The described combination also helps in reducing the wear characteristics of composite. Surface roughness for the same mentioned composition is found to be less and exhibit greater surface smoothness.

Rita Mourya et al[26] studied the effect of carbonaceous (graphite, carbon nano tubes and graphene) on Al6061 hybrid MMC processed using friction stir casting method. The results showed optimum mechanical and wear behaviour and enhanced tolerance towards damage caused while testing for wear.

Haowu et al[27] studied the mechanical and tribological composites of epoxy based composites by incorporating bio based reactive graphene oxide with a weight percentage of 0.1,0.25 and 0.5. Excellent mechanical and tribological properties were seen with good storage modulus, thermal stability and elasticity. Also, it was evident from tests that the prepared composites showed best wear resistance and low friction coefficient.

A Keshavalu et al[28] developed epoxy hybrid nano composites using epoxy base matrix and graphene nano platelets (synthesized using liquid phase exfoliation method from graphite)/alumina (nano). The nano platelets were dispersed in base matrix to prepare HNC. It was seen from the results that surface roughness (RA), hardness and friction coefficient were enhanced. Optimum reinforcement values were obtained to be graphene/0.2 wt.% and alumina/ 0.8 wt.%. The prepared HNC is suitable for critical applications in coating and bearing.

3.0 Materials and Fabrication Methods

3.1 6061 Aluminum Alloy

In the present study, 6061 aluminum alloy (Unified Numbering System (UNS) title A96061) is an alloy prepared by precipitation hardening, which contains magnesium and silicon as its major alloying elements. Initially it is known as Alloy 61S, it was developed in the year 1935[14]. This is having excellent mechanical properties, which exhibits very superior weld ability, and it is most regularly extruded (second in popularity only to 6063)[15]. It is the most general alloys of aluminum for common purpose use.

It is generally obtainable in pre-tempered grades for example 6061-O (annealed), tempered grades for example 6061-O (Artificially aged and solution zed aged) and 6061-O (stress-relieved stretched, artificially aged and solution zed).

3.2 Properties of Al6061

Annealed 6061 (6061-O temper) have highest ultimate tensile strength not more than 150 Mpa (22 ksi)[17,18] and

Table 1: Chemical Composition of Al6061

6061 Aluminum Alloy Composition by Mass %[16]									
Al	Mg	Si	Fe	Cu	Cr	Zn	Ti	Mn	Remainder
95.85 - 98.56	0.8 - 1.2	0.40 - 0.8	0.0 - 0.7	0.15 - 0.40	0.04 - 0.35	0.0 - 0.25	0.0 - 0.25	0.0 - 0.15	0.05 each, 0.15 total

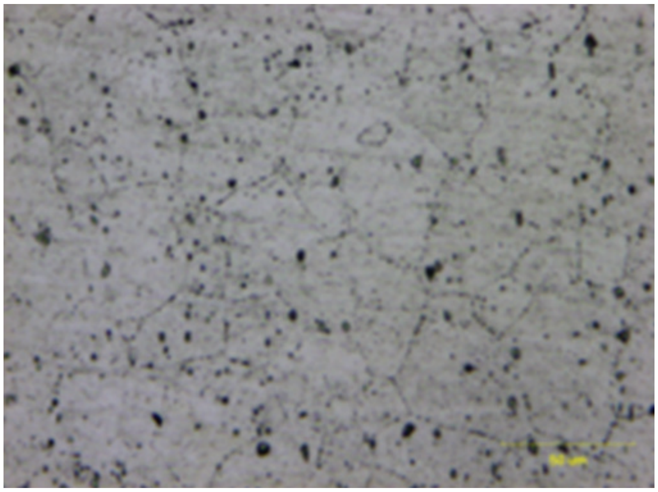

Figure 1: Grain boundaries in extruded plate 6061 aluminum alloy

maximum yield strength not more than 83Mpa (12ksi)[17] or 110Mpa (16 ksi)[18]. The material has elongation of 10-18%. To obtain the annealed condition, the alloy is typically heated at 415°C for 2-3 hours[19].

3.3 Microstructure

The different aluminum heat treatments manage the size and scattering of Mg_2Si precipitates in the material. The sizes of the grain boundary also vary, but it does not cause any significant impact on strength as the precipitates. Grain sizes can vary orders of the magnitude based on stress and can have grains as tiny as a few hundred nanometers, but are normally a few micrometers to hundreds of micrometers in diameter. Manganese, iron and chromium are secondary phases ($Fe_2Si_2Al_9$, $(Fe, Mn, Cr)_3$ $SiAl_{12}$) frequently form as inclusions in the material[20].

Grain sizes in aluminum alloys are heavily dependent upon the processing techniques and heat treatment. Different cross-sections of material which has been stressed can cause order of magnitude differences in grain size[21]. Some specially processed aluminum alloys have grain diameters which are hundreds of nanometers[22], but most range from a few micrometers to hundreds of micrometers[23].

3.4 Microstructure of Graphene Obtained

In order to determine the interplanar spacing of the atomic planes present in the material, the X-ray diffraction (XRD) technique (Shimadzu XRD 6000) was used, with a 2θ angle ranging from 5 to 70° and a wavelength of 1.5406 Å, at 40 kV and 30 mA. All samples were measured on an amorphous silicon sample holder. The X-ray diffract gram for graphite provided two characteristic peaks of this material at 2θ=26° (d002=0 34 nm) and 2θ=55° (d004=0 17 nm), corresponding to planes (002) and (004), respectively.

The most prominent feature in the graphite spectrum is an acute G peak at around 1583 cm^{-1} corresponding to the vibrations in the graphite structure plane and a peak at around 1370 cm^{-1} corresponding to the disorder band, D. In the spectra of the films obtained here, we can see the presence of wide D and G bands, not so well resolved as for graphite. In the case of the GO film, this could be related to the insertion of functional groups during the oxidation of graphite, which increases the topological disorder of the material. Nevertheless, this behaviour remains for the reduced GO films (CGOF), indicating that this type of structure has not changed.

3.5 Extraction of Coconut Shell Ash Particulates

Dry coconut shells were gathered from the nearby agricultural area, oil mills and food production places. In order

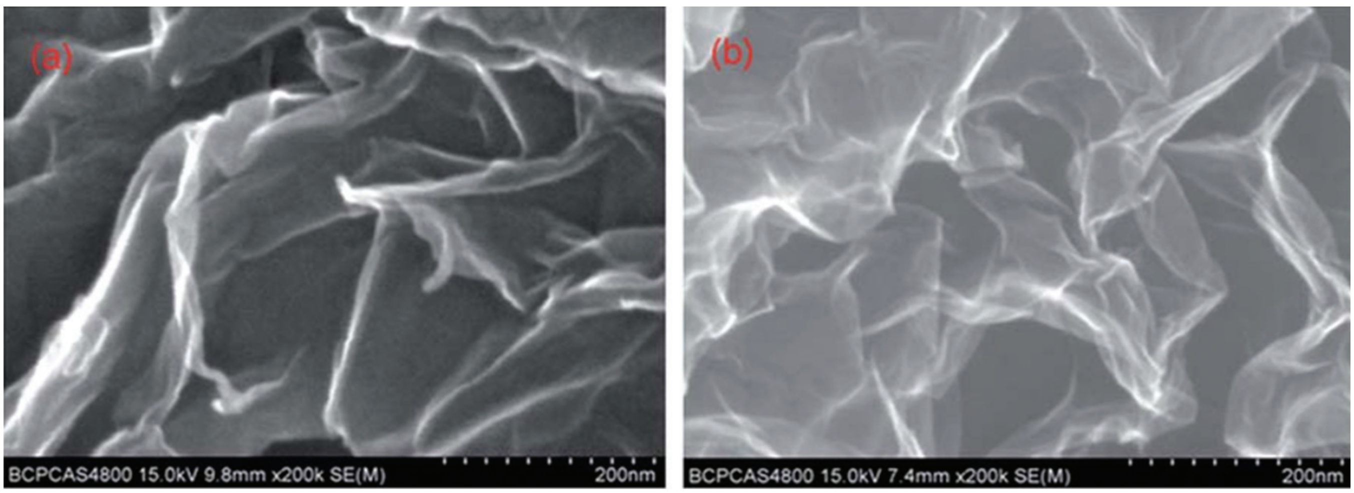

Figure 2: Microstructure of Graphene as obtained by Ultra nanotech Pvt Ltd

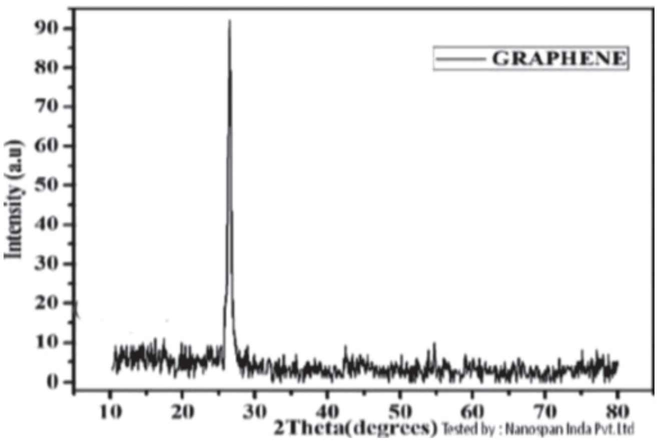

Figure 3: XRD analysis of Graphene obtained

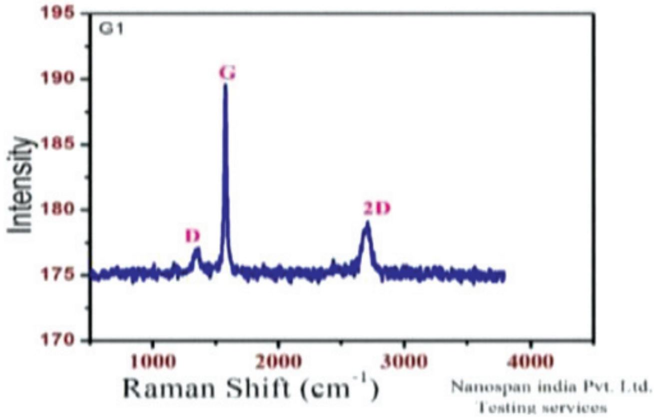

Figure 4: Raman analysis of Graphene as obtained by Ultra nanotech Pvt Ltd

Table 2: Characteristics of CSA [73]

pH Value	7.47
Ash content	68.5%
Moisture content	0.609%
Loss in ignition	11.5%
True density	1.65 g/cc
Average crystallite size	41.50 nm
Specific BET surface area	175.0777 m2/g
Average pore diameter 4.479 nm	4.479 nm

to remove the moisture content and dirt, the shells were cleaned and sun dried for two to three days. The dried coconut shells were pulverized to powder form and placed in graphite crucible, then burned in open air till the powder gets complete combustion. After the complete combustion in the open hearth, the coconut shell ash powders were allowed to hearth cooling at room temperature, before the removal of CSA from crucible to avoid the formation of charcoal. The whole process of converting coconut shell into CSA is done with reference to [73] and according to the reference the characteristics of CSA are listed below:

3.6 Fabrication of AMMC (Hybrid)

In this work, aluminum alloy (Al6061), shown in Table 1 in the form of rod of 100 mm diameter and 300 mm length is used as base material, while graphene with particle size in the range of (5-10) nm and CSA (This ash is sieved in order to get ash particle size of less than 150 µm) is used as reinforcement. The properties of Al6061 aluminum alloy is shown in Table. The density of the grapheme, CSA and Al6061 aluminum alloy is 3.1 g/cm^3, 1.65 g/cm^3 and 2.7 g/cm^3 respectively. Composite samples were prepared by varying graphene (0.2%, 0.4%, 0.6% and 0.8%), CSA (2%, 4%, 6% and 8%) by weight.

Stir casting process is one among the highly productive, low cost manufacturing techniques used to fabricate aluminum matrix composites for a wide range of processing conditions [74]. A charge of Al6061 alloy was placed in furnace inside a graphite crucible to heat up to 750^{o}C, along with 1.0 wt.% preheated flux and wt.% reinforcement at 300^{o}C in an oven. Argon gas was allowed to pass during melting of alloy to avoid oxidation. The furnace temperature was raised to 850^{o}C. Preheated flux was added to the melt and allowed for homogenization for 5-6 min by agitating of stirrer in the melt. After cleaning the surface of the melt, preheated (up to 300^{o}C) CSA and graphene particles were added into the vortex of the melt during stirring. The composite melt was stirred with stainless steel impeller at 300 rpm for 10 min. Then the melt is allowed into the die of 120 mm length and 90 mm with a thickness of 10 mm while stirrer is rotating. The same process is repeated for pure Al6061 alloy and also for reinforcement coconut shell Ash (CSA) 2%, 4%, 6% and 8% and graphene 0.2%, 0.4%, 0.6% and 0.8%. The ingots of the composites and unreinforced Al6061 alloy were subjected to a heat treatment for 24 hrs at 110^{o}C in muffle furnace [75]. The figures below show the whole process and equipment used.

4. Evaluation of Mechanical Properties

4.1 Density Distribution in the Composite Specimen

The density distribution is related to the distribution of fragments in MMC. The density was determined for small samplings taken at the top portion of MMC. The standard cylinder-shaped samples of 20 mm length and 14 mm diameter were utilized for these tests. Experimental density is calculated using density measuring instrument and the theoretical density for each sample is calculated using the below formula:

Theoretical density = (Density of matrix × vol fraction of the matrix) + (Density of reinforcement (1) × volume fraction of the reinforcement (1)) + (Density of the density of reinforcement (2) × volume fraction of the reinforcement (2))

Density Determination Kit is available in 2 types: one to be mounted on the pan and the other type is with attachment for weigh below the balance. Density Determination Kit consists of density weighing pan assembly, stainless steel base for beaker, glass beaker, optional sinker for testing materials having density less than water and software (programme) for density determination.

Range: 1mg - 1000g

4.2 Results of density test

The particle density of CSA determined was 2.05g/cm^3 v and graphene was 2g/cm^3 while the density of the Al6061 alloy was 2.67g.cm^{-3}. Since CSA and graphene has lower density than Al6061 alloy, its addition to the composite will make the density of the composite to be less than that of the alloy. At the same volume, Al 6061 + CSA + graphene composite will weigh less than aluminum alloy. It was observed that the addition of CSA and graphene into the Al 6061 alloy matrix significantly decreased the density of the resultant composites in comparison with the base alloy (Fig).

Table 3: Density results by theoretical and experimental methods

Wt %age of graphene	Wt %age of CSA	Theoretical density (g/cm^3)	Experimental density(g/cm^3)
0	0	2.7	2.71
0.2	2	2.6636	2.643
0.4	4	2.6596	2.654
0.6	6	2.6364	2.623
0.8	8	2.6152	2.592

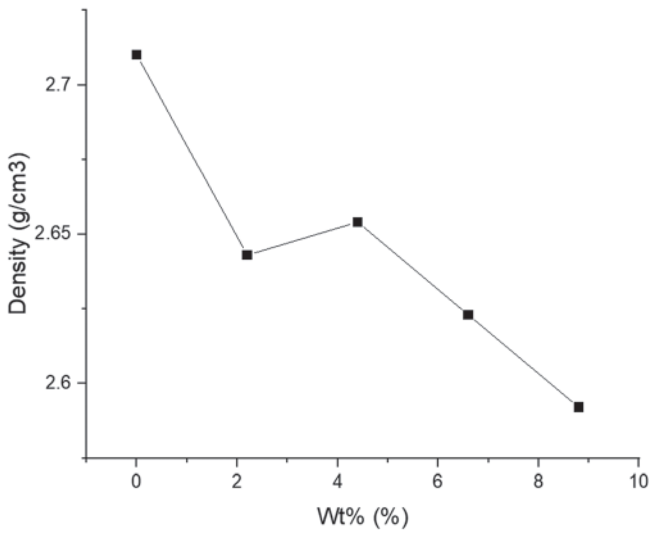

Figure 5: Density values with the varying percentage of CSA+C

4.3 Tensile Test

In order to study the mechanical characteristics of the composites, the tensile examinations were performed using advanced computerized universal testing machine according to ASTM standards. The dimensions of the specimens are shown in Figure. The tensile properties, such ultimate tensile strength and % elongation were determined from the stress-strain curves. The examination has been executed using computerized universal testing machine (UTM) shown in Figure, by the ASTM E-8 standards. The specimen was prepared by wire cut EDM machine according to the standard required.

The tensile tests were carried out as per the mentioned standards using the equipment. The values of ultimate tensile strength, yield strength and percentage elongation is obtained and tabulated in Table 4.2. The graphs of AMMC with different wt% of reinforcement's vs tensile test results are plotted and shown below.

Influence of CSA and graphene particles on yield strength and Ultimate Tensile Strength (UTS) of aluminum composite. It can be observed that the strength of composite increased

Table 4: Tensile test results

Wt %age of CSA	Wt %age of Graphene	Tensile strength (N/mm^2)	Yield strength (N/mm^2)	Percentage elongation
0	0	178.28	135.29	8.2
2	0.2	189.56	149.77	9.1
4	0.4	201.38	178.15	8.7
6	0.6	232.98	189.02	7.2
8	0.8	255.23	196.69	6.8

with increase in CSA+C up to 8% by weight. The UTS increased up to 43.16% and the yield strength increased up to 45.38% when compared to that of the base aluminum alloy. Increase in UTS and yield strength may be due to the interfacial bonding between the soft aluminum matrix and the hard CSA+C. Similar trend is observed while in the literature but with different reinforcement materials. It can be observed from Figure 4 that elongation of the composites decreases with further increase in CSA+C content and the same is supported by the literature with SiC, Al_2O_3 and other particulates. Reduction of elongation percentage is about 17% in this work as compared to the base metal alone. This may be due to the reason that the elongation decreases with the increase in the UTS and yield strength as the ductility is

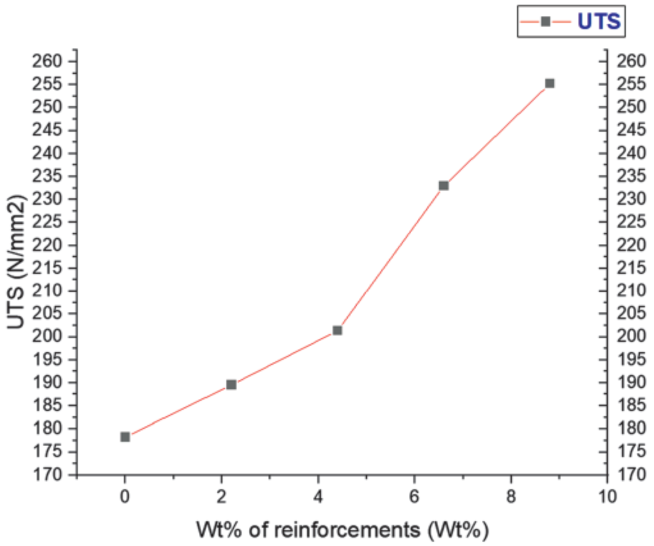

Figure 6: Tensile strength v/s wt% of reinforcements

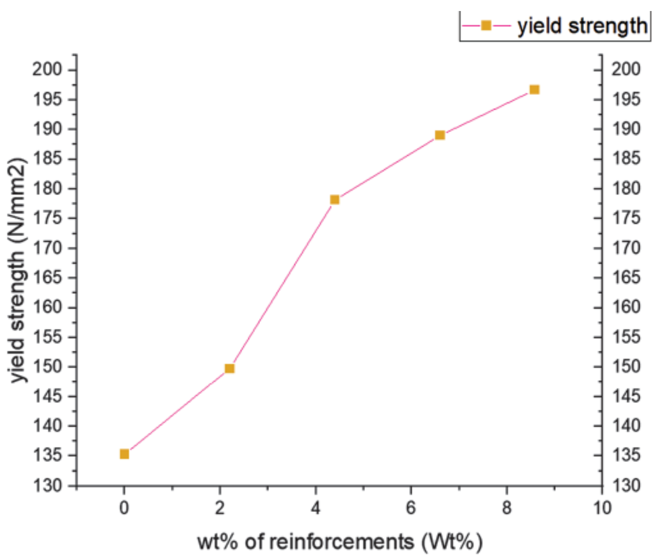

Figure 7: Yield strength v/s wt% of reinforcements

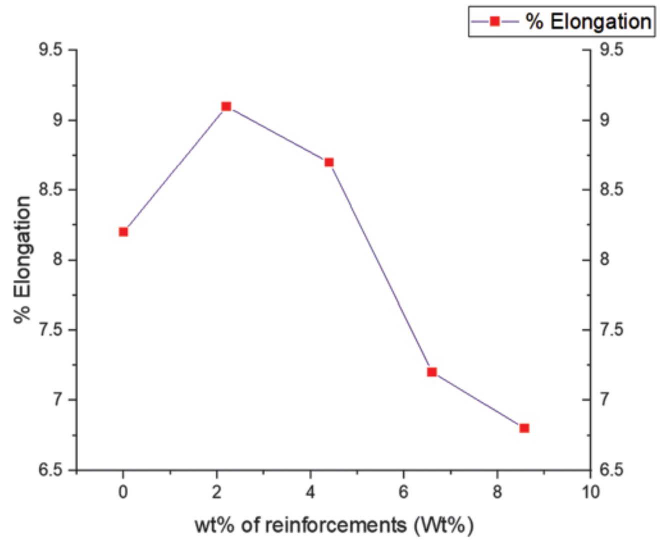

Figure 8: Percentage elongation v/s wt% of reinforcements

decreased (Brittle nature of the composite). Increase in the percentage of CSA+C particles increases the interfacial bonding between the base metal and the reinforcement. With the addition of further reinforcement particles the elastic deformation is reduced and the plastic deformation is increased or promoted. While even the further addition of CSA+C particles which are hard and sharp in nature influence the formation of cracks and initiated deboning of base metal and reinforcement which leads to elastic deformation and then to immediate fracture due to increase in the load.

The quantities clearly indicate that the highest strength, ductility and toughness are obtained in the sample with 8.8 wt% CSA+C. The increase in the yield strength, tensile strength, and in the sample containing 8.8 wt% CSA+C with respect to the pure aluminum alloy sample were about 43.16 and 45.38%.

The strengthening increment of reinforcement on the Al matrix (R), can be based on the below equation:

$R = 100X\ (\sigma c - \sigma m)/\sigma m$

Where, σc and σm are the UTS of the composite and matrix, respectively. As a conclusion, CSA+C can play a role of desirable filler material in AMMCs. The strengthening capacity of CSA+C in the composites can be better recognized by comparing its strengthening and stiffening efficiency with those of other Al matrix composites strengthened by other published reports.

The even and uniform distribution of reinforcements and precipitation of graphene in the matrix (seen in micro structural evaluation) enhance the mechanical properties.

4.4. Hardness Measurements

The specimens prepared as per ASTM standards were subjected to Micro Vickers Hardness test, and the results obtained are tabulated and presented in Table 5. The data presented in Table 5 and illustrated in Fig.4 clearly indicates that there is a variation of hardness. The hardness of Al-6061 with 2.2 wt.% CSA+C is 6% higher than the base metal (Al-6061). Similarly the hardness of Al-6061 with 4.4 wt.% CSA+C composite is 14.92% higher than that of base metal (Al-6061). The hardness of composite with 6.6 wt% CSA+C and 8.8 wt% CSA+C is 22.3% and 35.82% respectively. The probable reason for increasing the hardness by adding CSA and graphene as reinforcement materials may be due to arresting the motion of dislocation of the matrix lattice. Another interesting property of particulates is they render their property of hardness to the soft matrix.

In the prepared composite, even distribution of graphene has provided a denser solid material with increased hardness. According to Orowan looping mechanism, the addition of graphene acts as an interstitial atom in aluminum metal matrix composites which will hamper the dislocation movement [78], leading to reduction in ductility. Rashad et al. [79] also reported an increase in hardness due to the addition of graphene as a result of Orowan looping mechanism. Moreover, due to Hall-Petch effect, the increase in the grapheme particles also increases the hardness of the composites as discussed by Meyers et al. [80]. These are all the facts that attribute to the increase in the hardness of the AMMCs produced.

Table 5: Hardness Test Results

Variations of reinforcements (wt. %)	Load applied (grams)	Time (Sec)	HV	HV
Al6061	1000	10	68	
			67	67±0.5
			67	
2% CSA + 0.2% C	1000	10	71	71±0.5
			71	
			72	
4% CSA + 0.4% C	1000	10	76	77±0.5
			78	
			77	
6% CSA + 0.6% C	1000	10	80	82±0.5
			81	
			83	
8% CSA + 0.8% C	1000	10	89	91±0.5
			91	
			94	

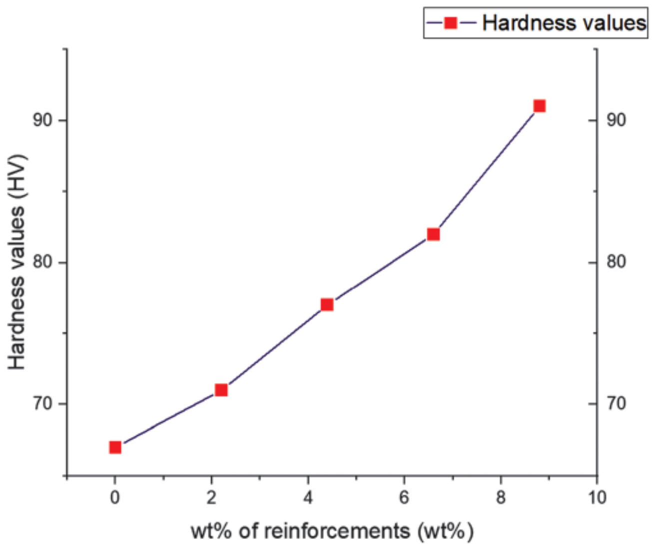

Figure 9: Hardness values v/s wt% of reinforcements

4.5 Observations Made

Scanning electron microscopy (SEM) was used to investigate the surface of pure Al and Al/CSA/C composite. SEM images of (a) pure aluminum, (b) Al/0.2 wt% grapheme/2 wt% CSA, (c) Al/0.4 wt% grapheme/4 wt% CSA, (d) Al/0.6 wt% grapheme/6 wt% CSA and (e) Al/0.8 wt% grapheme/8 wt% CSA, with EDS.

Microstructure of pure aluminum revealed good metallurgical bonding between the Al particles. Dark black regions are present due to oxidation during the fabrication process. In Al/CSA/C composite small dark spot like structures (precipitated with Al) are graphene while the white structures are CSA, which are uniformly distributed in the aluminum matrix. There is good chemical bonding between CSA/C and aluminum particles. The data presented in Figs 4.6a, b, c, d and e reveals the microphotographs of Al-6061, Al-6061 with 2.2% CSA/C, Al-6061 with 4.4% CSA/C, Al-6061 with 6.6% CSA/C and Al-6061 with 8.8% CSA/C respectively. From figures it is clear that, the homogenous distribution and excellent binding of reinforcing particulates in all the samples with varying wt% of reinforcement are fairly uniform. The size of the CSA and graphene particles appear to be uniform throughout the aluminum matrix. Metallographic examination reveals that the presence of reinforcement particles was observed on the matrix phase as thick black and white spots. Number of spots area increased in the matrix phases as the addition of CSA/C is increased and dispersed in matrix. With the increase in the wt% of reinforcements with proper magnification the distribution and appearance of CSA/C can be seen very clearly.

The particles are tightly packed with a homogeneous spatial distribution in each composite. Particulates are seen

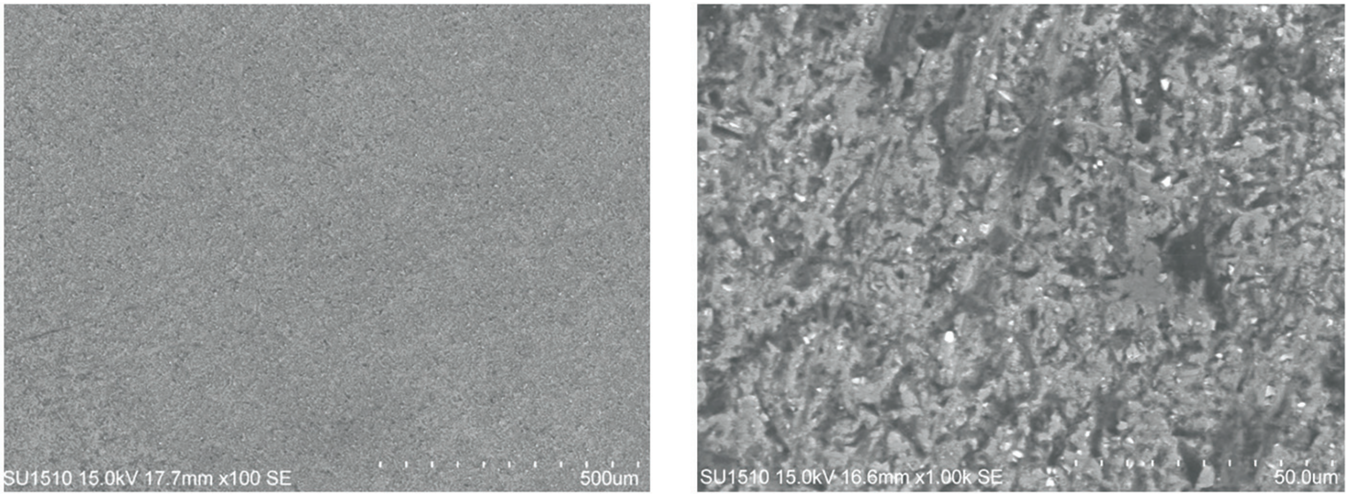

Figure 10: (f) SEM image of pure Al6061, (g) SEM image of pure Al6061/2% CSA/0.2% Graphene

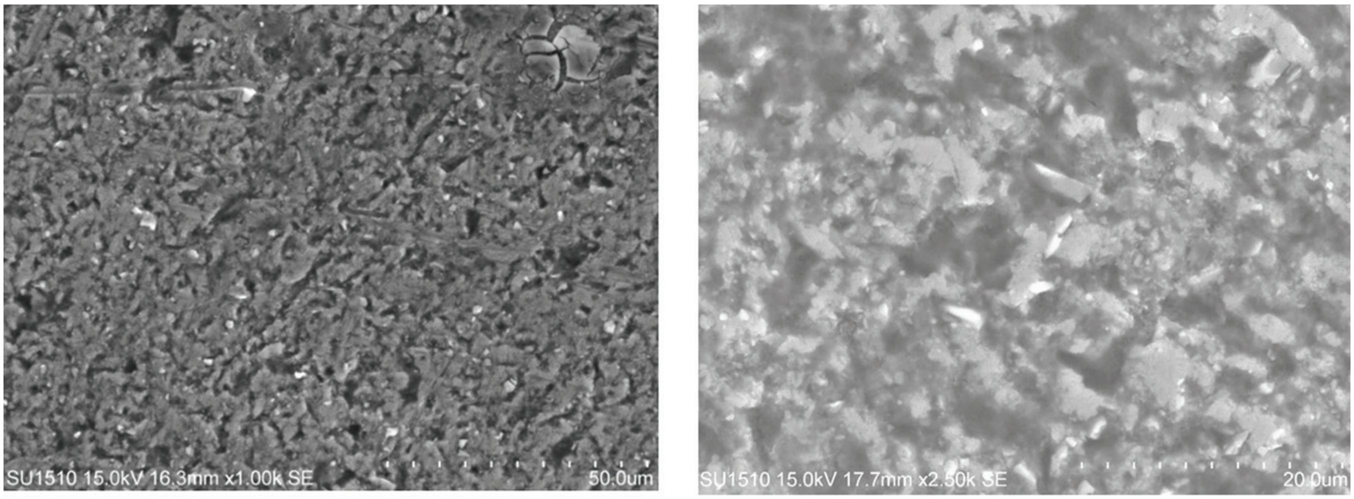

Figure 11: SEM image of pure Al6061/4%CSA/0.4% Graphene, i: SEM image of pure Al6061/6%CSA/0.6% Graphene

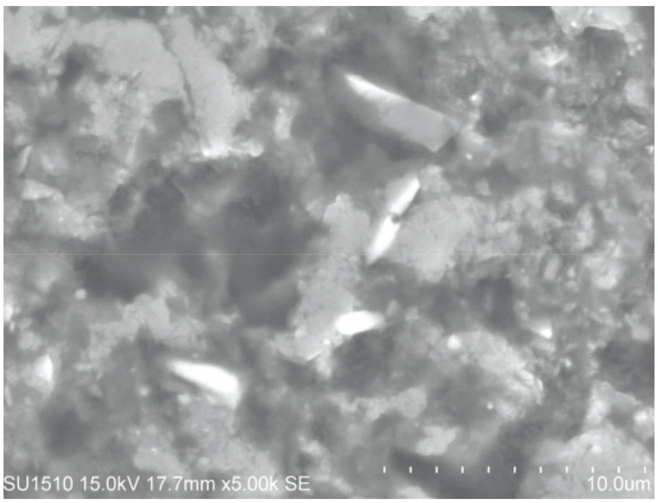

Figure 12: SEM image of pure Al6061/8%CSA/0.8% Graphene

in between the matrix in small sizes with grain boundaries and precipitated with the base metal and we can observe that the addition of reinforcements differ in structure increasing the porosity and mechanical defects and they are relatively large and oval grains. The CSA and graphene particulates are observed to be in irregular shape. The observation made in the study is on far with the experimental data conducted. Due to the uniform distribution of the particulates and precipitation formed between the matrix and reinforcements the mechanical properties are obviously enhanced.

5.0 Conclusion

It can be confirmed from the review made in this paper that the aluminum and its alloy become more favourite when MMC has to be fabricated due to its applicability with respect to its properties. To make the Al/Al alloy more suitable for critical applications the reinforcements are selected on the basis of their composition and properties which can in turn enhance the properties of MMCs. Here a detailed review is done to showcase the different reinforcements that can be used in developing MMCs as well as hybrid MMCs. Al_2O_3, SiC, B4c, fly ash, coconut shell ash, graphite, graphene, carbon nanotubes etc. are the reinforcements which can enhance mechanical, tribological as well as the thermal properties of the Al and its alloys by imparting strength, hardness, low density, good wear resistance, low friction coefficient and thermal conductivity. The application of these MMCs/HMMCs finds a vast area including automobile, aircraft, aerospace, nuclear engineering and many more.

6.0 References

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