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SYNTHESISAND CHARACTERIZATION OF ALUMINUM (4032) METAL AND NANO SiO_2 COMPOSITES FOR EVALUATING THEIR MECHANICAL PROPERTIES

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Abstract- ***Metal matrix composites (MMC's) have evoked a keen interest for automotive and small engine applications because they have preferable combinations of mechanical characteristics. In recent times, it could be noticed that development of the metal matrix composites (MMC's) has been emerged as a significant area of research in material science. The reinforcement in metal matrix composites is in the form of continuous or discontinuous fibers, whiskers or particulates, in various weight fractions. Among metal matrix composites, particulate reinforced AMC's are chosen due to their better mechanical and physical properties. Aluminum metal matrix composites exhibit desirable properties than individual conventional material used alone. The present investigation is aimed at evaluation of mechanical properties of Al 4032 reinforced with nano- SiO_2 at different wt% 0, 1, 2, 3 by stir casting method. The mechanical properties of MMC's viz., tensile strength, compression strength, impact strength and hardness strength, microstructure were characterized.***

Keywords- Metal Matrix Composites, Stir casting, Nano - SiO_2, Al 4032

I. INTRODUCTION

Composite materials are natural and manmade materials consisting of two or more constituents which give superior properties than those of the individual component used alone. The constituents of MMC's are having intimate contact with each other, with a recognizable interface between them which are not soluble in each other. As compared to metallic mixture, each and every material has its individual physical, chemical and mechanical properties. The two constituents are reinforcement or fortification and a matrix. The primary interest of composite materials are their high strength and stiffness, low density when compared to bulk materials, which provides a weight reduction in the finished part. In almost all cases, the fortification is harder, stronger and stiffer than matrix[1].

Metal matrix composites are class of newborn materials which are appealing for enthusiasm towards industrial and investment worldwide. Metal matrix composites are different from extensively grown organic polymer matrix composites because of their metallic character in respect of physical and mechanical properties such as electrical conductivity, thermal conductivity, shear strength, ductility and impart themselves to traditional metallurgical processing operations. They can resist to elevated temperatures in devastating conditions than organic polymer matrix composites. Most metals and its mixture employ as matrix and strengthening materials should be stable over extent temperature and non reactive too. The sort, form and spatial arrangement of the fortifying stage in metal matrix composites are the main variables in determining their mechanical properties. In processing of MMC's is to ability to select the appropriate matrix and a fortification material. Here, matrix materials employ in MMC's are aluminum, magnesium, aluminum-lithium, copper, titanium and super amalgams and the fortifying stage may be in the form of particulates, fibers, whiskers. Some of the major particulate fortified in composites materials is alumina, silicon carbide, fly ash, titanium carbide, boron carbide, quartz , graphite and so on. In specific, particulate fortified MMC's recently discovered special interest due to their specific strength and specific stiffness at room and hoisted temperatures. The enlargement of MMC's became great extent due to its low density and low cost fortifications[2].

Among above MMC's, aluminum is the most common matrix material because of its low density, good corrosion resistance, high thermal and electrical conductivity and damping capacity. The inclusion of hard and stiff ceramic stage has been entrenched to make better modulus behavior and strength properties in metallic matrices. For instance, the fortifying phase SiO_2 yields both physical and mechanical properties. Discontinuously fortified aluminum matrix composites are useful in many applications like engine piston, cylinder drum, transmission valves and so on [3]. According to I.A. Ibrahim et al., the processing methods[4] utilized to manufacture particulate reinforced MMCs can be grouped depending on the temperature of the metallic matrix during processing which includes liquid phase processes, solid state processes and two phases (solid-liquid) processes. The studies further revealed that the physical properties, strengthening in metal matrix composites has been related to dislocations of a very high density in the originating from differential thermal contraction, geometrical constraints and plastic deformation during processing.

Hasan Issa et al., Carried out experimental tests[5] on aluminum matrix composites reinforced with nano SiO_2 particles and the results revealed that adding just 1wt% SiO_2 nanoparticle increases both hardness and tensile strength by 41.8% and 24.8%, respectively. Further, the mechanical properties seemed to be decreased with increases in the SiO_2 weight fraction. The findings of this study expressed that the SiO_2 nanoparticle can be used as an effective reinforcing material for developing aluminum matrix nano-composites.

G.B. Mallikarjuna et al., literature survey[6] revealed that the synthesized Al alloy LM13- SiO_2 composites were produced by stir casting and the microstructures of the composites were studied to know dispersion of the SiO_2 particles in the matrix. The results revealed that the highest tensile strength was achieved in the specimen containing 12 wt% of SiO_2, in comparison to the unreinforced Al alloy. Further it has been observed that addition of SiO_2 particles significantly improves wear resistance, tensile strength and hardness properties as compared with that of the unreinforced matrix. B.M. Viswanatha et al., The investigation studies[7] of microstructure and mechanical properties of Aluminum Matrix composites (AMCs) reinforced with silicon carbide and graphite particles. A356 alloy is used as the matrix material with varying the reinforcement of SiC from 0 to 9 wt% in steps of 3wt% and fixed quantity of 3wt% of graphite. The composites were fabricated by liquid metallurgy method. The prepared composites were examined for microstructure to know the particle distribution in the matrix material. Hardness and tensile properties were studied and compared with the alloy. The research results confirmed significant improvement in hardness and tensile properties by increasing the weight percentages of SiC particles.

II. MATERIALS AND METHODS

Al 4032 is chosen as matrix material, because of its high strength, low coefficient of thermal expansion, heat-treatable, good corrosion resistance and good flow characteristics. In 4xxx series, silicon is the major alloying element. Al 4032 is broadly used in forging pistons, master brake cylinders, transmission valves, bushings for rack and pinion steering systems. The details of chemical composition of Al 4032 are presented in table-1.

Table 1: Chemical Composition of Al 4032

Composition	Weight percentage (%)
Al	85
Si	12.20
Mg	1.0
Cu	0.90
Ni	0.9

The fortified material used in the present work was amorphous SiO_2. SiO_2 was procured in the form of nano particles, particle size of 60-70nm, Particle density of 2.4 g/cm^3, melting point of 1713^{0}C and boiling point of 2950^{0}C.

The method used for production of metal matrix amalgamation is stir casting**.** Stir casting is one of the liquid state process in which dispersed stage is blended with a liquid matrix metal by means of manual blending to avoid clustering and sedimentation in the melt. In the present work, Al 4032-SiO_2 metal matrix amalgamation are prepared by stir cating method. For this purpose, muffle furnace with temperature controlling device was utilized for melting. Al 4032 is procured in the form of ingots. By using hydraulic hack saw the Al 4032 is made into pieces. The pieces are wiped before placing in graphite crucible. At first, pure Al 4032 metal pieces were melted in a furnace upto 760^{0}C. At this stage, small quantities of Mg were added as a wetting agent. Then suitable amount of 1% wt of the base metal of SiO_2 was added slowly to liquefy metal. SiO_2 added to the liquefy metal was pre-warmed to remove the moisture and stirred continuously. The liquefy composites poured into prepared moulds to get required tensile, compression, izod and charpy specimens. Same procedure was continued at different weight percentages 2%, 3% to get required Al 4032-SiO_2 amalgamation.

Tensile Test:

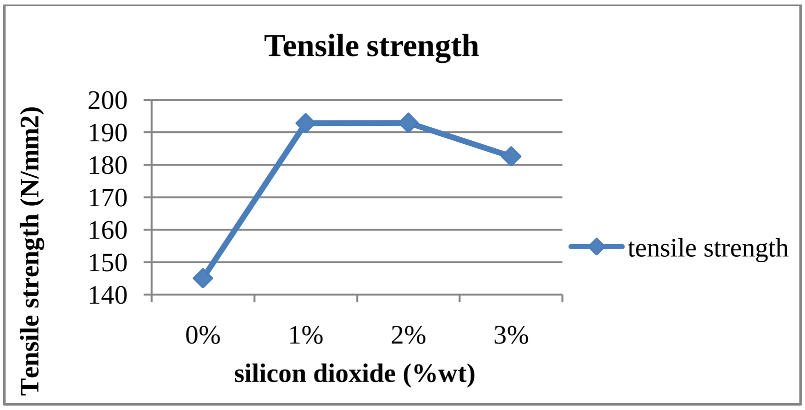
The ultimate tensile test was carried out on a computerized universal testing machine at room temperature in accordance with ASTM-E8 standards. Each specimen of Al 4032 matrix fortified with SiO_2 in different wt% i.e 0, 1, 2, 3 are subjected to tensile test. The tensile test specimens were produced using CNC machine according to the required dimensions.

Table 2: Tensile strength values for Aluminum 4032 and SiO_2 of different compositions

Material of the test Piece	Al 4032 (gms)	Weight of SiO_2 (gms)	Tensile strength (N/mm^2)	Elongation (%)
Al 4032+ 0% SiO_2	135	0	144.98	2.40
Al 4032+ 1% SiO_2	133.65	1.35	192.77	2.20
Al 4032+ 2% SiO_2	132.3	2.7	192.83	2.16
Al 4032+ 3% SiO_2	130.95	4.05	182.51	2.14

Fig 1: Tensile specimens before testing

Fig 2: Tensile specimens after testing



Graph 1: Variation of tensile strength and % reinforcement.

Compression Test:

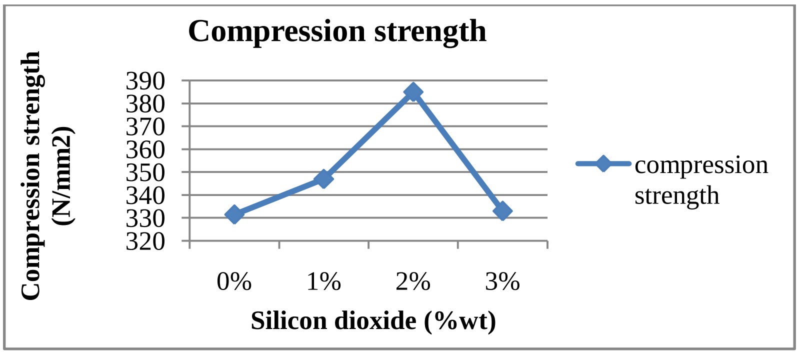
When the specimens are subjected to flattened, crushed, squashed or compressed, it exhibits the different elementary behavior beneath a compressive load. The compressive test was performed on a computerized universal testing machine in accordance with ASTM-E9 standards. Each specimen of Al 4032 matrix fortified with SiO_2 in different wt% i.e 0, 1, 2, 3 are subjected to compression test. The compression test specimens were prepared using lathe machine according to the dimensions.

Table 3: Compression strength values for Aluminum 4032 and SiO_2 of different compositions

Material of the test Piece	Al 4032 (gms)	Weight of SiO_2 (gms)	Compression strength (N/mm^2)
Al 4032+ 0% SiO_2	259.2	0	331.49
Al 4032+ 1% SiO_2	256.608	2.592	347.05
Al 4032+ 2% SiO_2	254.016	5.184	387.01
Al 4032+ 3% SiO_2	251.424	7.776	332.99

Fig 3: Compression specimens before testing

Fig 4: Compression specimens after testing



Graph 2: Variation of compression strength and % reinforcement

Izod Test:

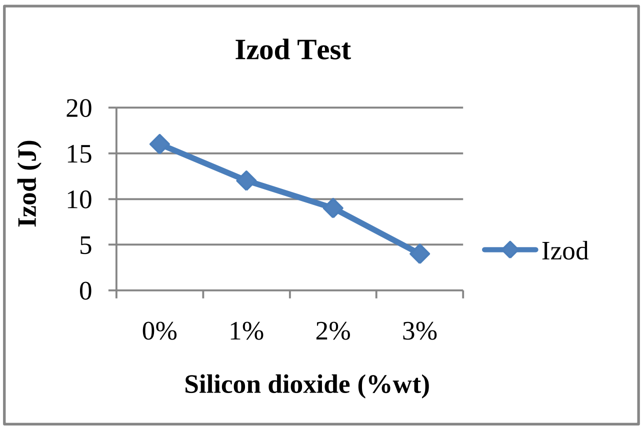
The Izod testing was carried out on impact testing machine in accordance with ASTM-E23 standards. Each specimen of Al 4032 matrix fortified with SiO_2 in different wt% i.e 0, 1, 2, 3 are subjected to izod test. The izod test specimens were prepared using shaping machine according to the required dimensions.

Table 4: Impact strength (Izod) values for Aluminum 4032 and SiO_2 of different compositions

Material of the test Piece	Al 4032 (gms)	Weight of SiO_2 (gms)	Impact strength Izod (J)
Al 4032+ 0% SiO_2	108	0	16
Al 4032+ 1% SiO_2	107.99	1.08	12
Al 4032+ 2% SiO_2	105.84	2.16	9
Al 4032+ 3% SiO_2	104.76	3.24	4

Fig 5: Izod specimen before testing

Fig 6: Izod specimens after testing



Graph 3: Variation of impact strength (izod) and % reinforcement

Charpy Test:

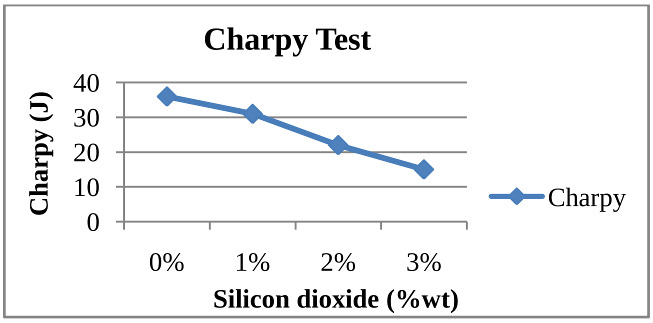
The charpy testing performed on impact testing machine in accordance with ASTM-E23 standards. Each specimen of Al 4032 matrix fortified with SiO_2 in different wt% i.e 0, 1, 2, 3 is subjected to charpy test. The charpy test specimens were prepared using shaping machine according to the dimensions.

Table 5: Impact strength (charpy) values for Aluminum 4032 and SiO_2 of different compositions

Material of the test Piece	Al 4032 (gms)	Weight of SiO_2 (gms)	Impact strength Charpy (J)
Al 4032+ 0% SiO_2	100.98	0	36
Al 4032+ 1% SiO_2	99.9702	1.0098	31
Al 4032+ 2% SiO_2	98.9604	2.0196	22
Al 4032+ 3% SiO_2	97.9506	3.0294	15

Fig 7: Charpy specimens before testing

Fig 8: Charpy specimens after testing



Graph 4: Variation of impact strength (charpy) and % reinforcement

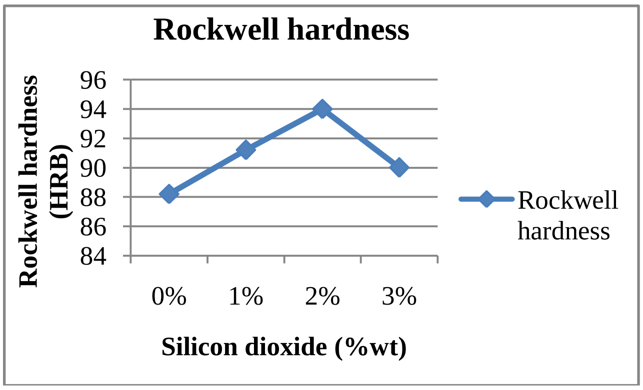
Rockwell Hardness Test:

The hardness testing was carried out on a rockwell hardness testing machine in accordance with ASTM-E18 standards. Each specimen of Al 4032 matrix fortified with SiO_2 in different wt% i.e 0, 1, 2, 3 is subjected to hardness test. A 1/16" ball indenter was impressed on material at a load of 100 kgf for 20 seconds. Five readings are taken to avoid segregation effect of the fortifications in the matrix.

Table 6: Hardness values for Aluminum 4032 and SiO_2 of different compositions

Material of the test piece	Rockwell hardness
Al 4032+ 0% SiO_2	88.2
Al 4032+ 1% SiO_2	91.2
Al 4032+ 2% SiO_2	94
Al 4032+ 3% SiO_2	90

Fig 9: Rockwell specimens after testing



Graph 5: Variation of rockwell hardness and % reinforcement

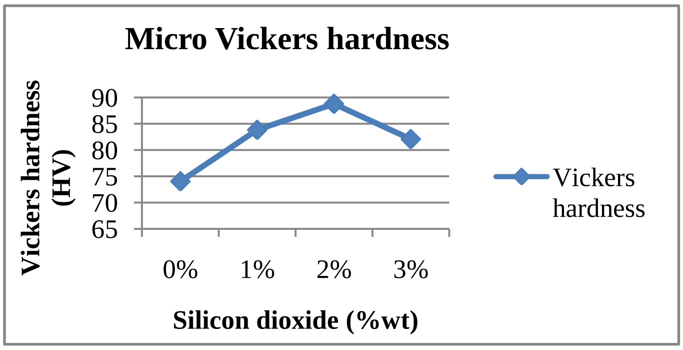
Vickers Hardness Test:

Hardness of the specimens was carried out on a Vickers hardness testing machine in accordance with ASTM-E92. A diamond indenter was impressed on sample at a load of 200 grams for 15 seconds. Five readings are taken for every sample to avoid segregation effect of the fortification in the matrix.

Table 7: Vickers hardness values for Aluminum 4032 and SiO_2 of different compositions

Material of the test piece	Vickers hardness
Al 4032+ 0% SiO_2	74.012
Al 4032+ 1% SiO_2	83.818
Al 4032+ 2% SiO_2	88.772
Al 4032+ 3% SiO_2	82.046

Fig 10: Vickers hardness specimens after testing



Graph 6: Variation of vickers hardness and % reinforcement

Microstructure:

Microstructures of the amalgamation were perceived to divulge the dispensation of nano particles SiO_2 in Al 4032 matrix. Specimens were buffed on emery papers of different grades and then cloth buffing with fine alumina powder on rotating disc. Microstructures are observed in unetched condition using image analyser at 400X magnification.

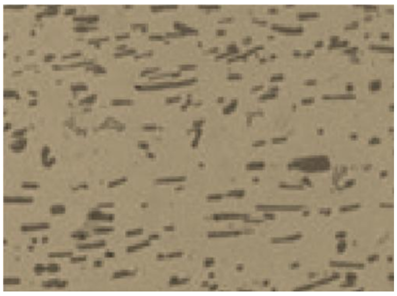


Fig 11: Microstructure of Al 4032

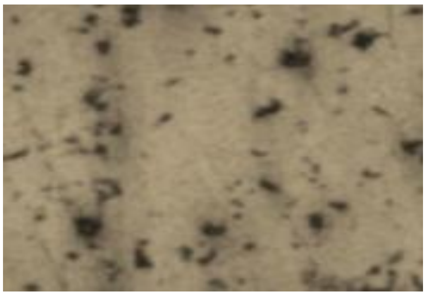


Fig 12: Microstructure of 1 Wt% SiO_2 fortified Al 4032

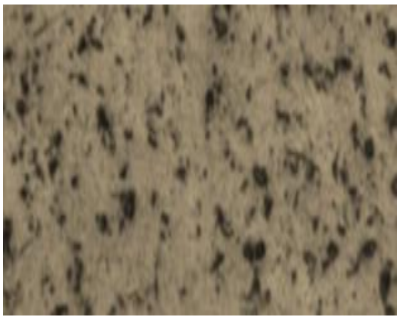


Fig 13: Microstructure of 2 Wt% SiO_2 fortified Al 4032

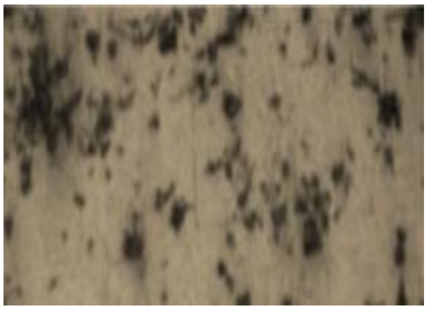


Fig 14: Microstructure of 3 Wt% SiO_2 fortified Al 4032

III. RESULTS AND DISCUSSION

- The variation in tensile strength with its fortification particles are presented in table 2. It shows that all the evolved composites have high ultimate tensile strength than unfortified alloy. Al 4032 fortified with SiO_2 at 3 wt% have less tensile strength compared to Al 4032 fortified with SiO_2 at 1, 2 wt%. Decrease in tensile strength at 3 wt% is due to effect of segragration of SiO_2 particles in Al 4032.
- The variation in compression strength with its fortification particles are shown in table 3. It shows that all the evolved composites have ultimate compression strength compared to unreinforced alloy. Al 4032 fortified with SiO_2 at 3 wt% have less compression strength compared to Al 4032 fortified with SiO_2 at 1, 2 wt%. The reduction in compressive strength at 3 wt% is due to agglomeration and non uniform distribution of SiO_2 particles in Al 4032.
- The impact strength viz., izod and charpy of Al 4032 fortified with SiO_2 amalgamation are shown in table 4 and table 5. It has been noticed that toughness for izod and charpy test decreased by addition of SiO_2 particles in Al 4032. This is due to the addition of SiO_2 in various percentages with Al 4032, the fragile of the material also increased. Because of its high fragility, the impact strength of the composites is reduced.
- The resistance of materials against mechanical indentation or abrasion is known as hardness. The macro and micro hardness assess the interface joining between matrix and fortified particles. From above table 5 and 6 it shows that %wt increase of SiO_2 particles in Al 4032 matrix amalgamation improves the hardness compared to unfortified alloy. Al 4032 fortified with SiO_2 at 3 wt% have less rockwell and vickers hardness compared to Al 4032 fortified with SiO_2 at 1, 2 wt%. The reduction is due to agglomerations and non uniform dispensation and also prevents the motion of dislocations during plastic deformation.
- The properties of the amalgamation rely on microstructure and interface feature between matrix and fortification. Figure 11, Figure 12, figure 13 show the microstructures of 1, 2, 3 wt% SiO_2 fortified Al 4032. From microstructural examination, agglomeration and non-uniform dispensation of SiO_2 particles in Al 4032 matrix were perceived. This was due to the difference `in contact time between SiO_2 and liquefies Al 4032 during amalgamation technique, elevated surface tension. Non-uniform dispersion of SiO_2 particles in Al 4032 can be perceived in the microstructure of 3 wt% SiO_2 fortified shown in fig 14. Porosites were oberseved because air entrapped in the melt between the particles during casting.

IV. CONCLUSIONS

Al 4032-SiO_2 based Metal matrix composites upto 3 %wt were suceessfully fabricated by stir casting technique. From above experimental observations the following conclusions were drawn.

1. Addition of SiO_2 in Al 4032 improves the tensile strength, compression strength, rockwell and vickers hardness compared to unfortified amalgamation. At 3 wt% SiO_2 fortified Al 4032 have less tensile strength, compression strength and hardness to 1, 2 wt% SiO_2 fortified Al 4032. The highest tensile strength, compression strength and hardness obtained at 2 wt%.

2. Addition of SiO_2 in Al 4032 gradually decreases the impact strength i.e izod, charpy compared to unfortified amalgamation.

3. Agglomeration and non-uniform dispersion of SiO_2 particles in Al 4032 were perceived in the microstructures at 3 wt%.

From the above results , SiO_2 fortified Al 4032 has better tensile strength, compression strength and hardness than unfortified amalgamation.

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