Evaluation of Mechanical Properties of Aluminium-4032 Reinforced With Silicon Dioxide

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Abstract- *Now a days, the researchers are focused on light weight and high strength materials for substituting the existing heavy weight materials. This is compensated by using the metal matrix composites. Among the different metal matrix composites the AMC's are preferred due to their preferable mechanical and physical properties. In this scenario, some of the researchers are substituting the aluminium-4032 piston in place of cast iron pistons but it is limited to small I. C. Engines. The present investigation is done on Aluminum-4032 reinforced with Silicon dioxide at various weight percentages (0, 1, 2 & 3 wt %) through stir casting route. Here the investigation focused on mechanical properties like tensile and compression strength, impact strength and hardness also were examined microstructure.*

Keywords- composite material, alluminium alloy, SiO2, Stirr castimg, Mechanical Testing and microstructure.

I. INTRODUCTION

Composite materials are manmade materials consisting of two or more constituents which give superior properties than those of the individual components used alone. The constituents are having intimate contact with each other and 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 of interest of composite materials are their high strength and stiffness, low density when compared to bulk materials, which provides a less weight in the finished part, the reinforcing phases provide strength and stiffness. In almost all cases, the fortification is harder, stronger and stiffer than matrix.

1.1 CONCEPT OF COMPOSITE:

Fibers or particles embedded in matrix of another material are the best case of advanced composite materials, which are mostly structural. Overlays are composite material where separate layers of materials give them the certain character of a composite to perform the specific function. Fabrics have no matrix to fall back on, however in them; fibers of different compositions incorporate to give them a particular character. Fortified materials resisted to extreme loads and serve the alluring properties..

1.2 CLASSIFICATION OF COMPOSITES:

Composites are generally classified into two distinct levels.

- According to type of matrix constituent, the first level classification includes ceramic matrix composites(CMC'S),organic matrix composites(OMC'S) and metal matrix composites(MMC'S).The term organic matrix composites is generally assumed to include polymer matrix composites(PMC'S) and carbon matrix composites.

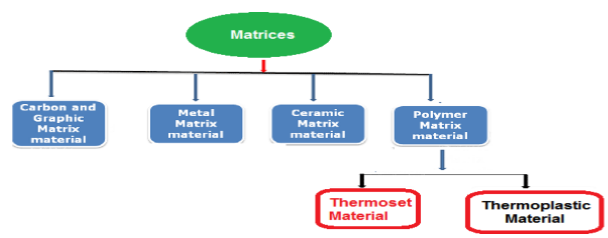


Figure 1: Classification of matrix materials

- Laminar composites are composed of layers of materials held together by matrix whereas particulate composites are composed of particles embedded in a matrix form and the particles may be flakes or in powder form.

1.2.1 Metal Matrix Composites (MMC):

Metal matrix composites, at present which producing a wide attentiveness in research brotherhood, are not generally used as their plastic counterparts. High strength, fracture toughness and stiffness are provided by metal matrices than those provided by polymer counterparts. They can withstand raised temperature in caustic condition than polymer composites. Most metals and mixture could be utilized as matrices and they require fortified materials which would be steady over range of temperature and non- reactive as well. However the directing aspect for the option depends basically on the matrix material.

1.2.2 Ceramic Matrix Materials (CMM):

Ceramics can be depicted as hard materials which shows strong ionic bonding and in some cases covalent bonding. High liquefying points, good damaging resistance, stability at raised temperatures and high compressive strength, render ceramic based matrix materials a special based for applications requiring a structural material that doesn't give route at temperature above 1500ºC. Naturally, these matrices are used for high temperature applications.

1.2.3 Reinforcements:

A powerful, inactive woven and nonwoven fibrous material included into the matrix to enhance its metal glass and physical properties. Usually fortifications are asbestos, boron, carbon, metal glass and ceramic fibers, rush, graphite, jute, sisal and whiskers, chopped paper, macerated textures and artificial fibers. The main contrast between fortification and filler is the fortification notably enhances tensile and flexural strength, whereas filler does not normally. Additionally to be viable, fortification must shape a strong cement bond with the resin. The part of the fortification in a composite material is basically one of the expanding the mechanical properties of the tidy resin system. The majority of separate fibers utilized in composites has separate properties and impact the properties of the composites in various ways.

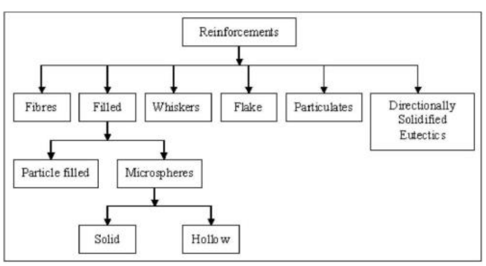


Figure 4 : Reinforcements

1.2.4 Particulate Reinforced Composites:

Microstructures of metal and ceramic composites, which exhibit particles of one stage strewn in the other, are meant as particle fortified composites. Square, triangular and round forms of fortification are known, however the measurements of all their sides are noticed to be more or less equal. The size and volume concentration of the dispread dissertates it from dispersion solidified materials. The dispersed size in particulate composite is of the sequence of couple of microns and volume concentration is prominent than 28%. The distinction between particulate composite and dispersion hardened ones is, consequently, unawares. The mechanism used to fortify each of them is too distinct. The dispersed in the dispersion reinforced materials are fortifies the matrix amalgam by apprehending movement of dislocations and needs great forces to rupture limitation generated by dispersion.

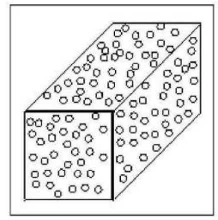


Figure 5: Particulate composites

1.2.5 Liquid State Fabrication:

Liquid state fabrication of Metal Matrix composites entail in including the dispersed stage into a molten matrix metal, come after its solidification. Basically, the various methods are

- Stir casting
- Infiltration
- Gas pressure infiltration
- Squeeze casting infiltration
- Pressure die casting

1.2.6 Stir casting:

It is a liquid condition procedure of composite materials manufacture, in which a dispersed stage such as ceramic particles, short fibers are assorted with a liquid matrix metal by intends of mechanical stirring. Stir casting is the uncomplicated and the most cost effective method of liquid state manufacturing. In this procedure particles are frequently forms accumulation, which can be liquefy by enormous stirring. But here gases enter into the melt should be eluded, otherwise lead to porosities or reactions.

II. MATERIAL SURVEY

2.1. MATRIX MATERIAL:

Aluminum alloy 4032 is chosen as matrix material on account of its medium strength, low coefficient of thermal expansion, heat-treatable, good corrosion resistance and good flow characteristics. In aluminum alloy 4032, silicon is the major alloying element. Aluminum alloy 4032 broadly used in forged pistons, master brake cylinders, transmission valves, bushings for rack and pinion steering systems.

Table 1: Chemical Composition of Al 4032

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

Fig 6: Aluminum alloy 4032 ingot

2.2. REINFORCEMENT CHOICE:

2.2.1. Silicon dioxide (SiO_2):

Silicon dioxide is also called as silica, which is an oxide of silicon with chemical formula SiO_2, very often occur in nature as quartz and in diverse living organisms and also known for its firmness since antiquity. In various parts of the world, silica is the critical component of silica. Also, silica is the most ample in earth crust. It is prevailing as amalgam of various minerals and as artificial product.

Silica exists in nine disparate crystalline forms or polymorphs with the three principal forms quartz, tridymite and cristobalite. Fibrous forms have the widespread name chalcedony and incorporate semi-precious stone sorts like agate, onyx and carnelian. Granular sorts incorporate jasper and flint and also anhydrous forms diatomite and opal. Large part of the products vend for industrial utilization are called silica sand. The word "sand" refers to a material whose grain size distribution within the range 0.06 to 2.00 millimeters.

The so called "amorphous silica" is utilize here for the pure shapes of SiO_2 like colloidal silica, precipitated silica, silica gel, pyrogenic silica, silica fume, quartz glass, fused silica and also framework of Radiolaria and diatoms in the shape of diatomaceous earth. Synthetic amorphous silica (SAS) comprise of nano-sized primary particles of nano- or micrometer-sized collection and of mass in the micrometer-size range. Hence these materials fall into definition of nanostructure materials.

2.2.2. Synthetic amorphous silica:

Synthetic or amorphous silica's are yielded through

- As wet process silica's
- As thermal route
- As silica sols

As wet process silica‟s: Precipitated silica and silica gel also called as silica aerogel are generated by restrained polymerization and precipitation of synthetic amorphous silica's from a solution of sodium silicate. SAS powders generated from wet route comprise huge amounts of leap water. Furthermore, they have an amorphous form.

As thermal route: pyrogenic silica, also called as fumed silica which is generated by the vapor stage hydrolysis of chlorosilanes in an oxygen and hydrogen flame at temperature approximately 1000^0c. At elevated temperatures produces a SAS powder has low water content and is amorphous.

As silica sols: Silica sols also called as colloidal silica's are steady scatters of SAS particles in a fluid, usually water. Sols may be directly yielded by hydrolysis of silicon tetrachloride in aqueous solution or polymerization of sodium silicate. Sols may also be implicitly yielded by re-dispersion of SAS particles into a fluid.

2.2.3. Properties of SiO_2:

Table: 2 properties of SiO_2

Properties	Values
Tensile strength	25 N/mm^2
Melting point	1713^{0}c
Boiling point	2950^{0}c
Density	2.4 g/cm^3
Thermal conductivity	1.3 W/m-k
Compressive strength	2070 N/mm^2
Poison's ratio	0.17
Modulus of elasticity	70Gpa

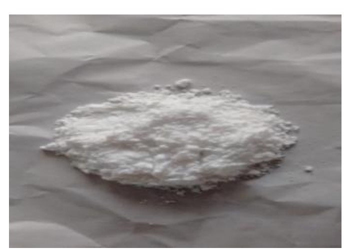


Fig 7: Silicon dioxide nano powder.

2.2.4. Properties of Aluminum Alloy 4032:

- Machinability: Machinability of aluminum amalgam 4032 is assessing as fair to good. Use of lubricating oils during machining is recommended.
- Forming: This is a forging amalgam and forming is done by hot die forging.
- Welding: This amalgam is weldable and utilization of inert-gas arc welding is the recommended method. Gas welding should be avoided.
- Heat Treatment: In this amalgam, solution heat treatment is done at 950^0F for 1 to 12 hours based on the thickness of the section. Cold water quench.
- Forging: Aluminum amalgam 4032 is a forging amalgam and hot die forging is done at temperature range of 510 to 371^0C.
- Hot Working: The identical comments as for "forging" is applied to hot working.
- Cold Working: This amalgam is basically a hot forged, cannot be cold worked.
- Annealing: Annealing of this amalgam can be done at 413^0C (775^0F) for certain amount of time through heating, followed by controlled cooling manner at rate of 50^0F (10^0C) per hour to 400^0F (204^0C) then air cool.
- Aging: The amalgam may be aged (T6 temper) by first solution heating at 950^0F and cold water quenching, followed by a 340^0F heating for 10 hours and air cooling.

III. CALCULATION FOR MATERIAL WEIGHTS

In this paper, the aluminium metal matrix composites are prepared with four different weight percentage of reinforcement i.e. 0, 1, 2 and 3wt% of SiO_2. Also hear five different distractive mechanical tastings and microscopic study carried out for evaluating the mechanical properties and microstructure. So that for preparing the specimens, the calculations done with respective length of the casted rod for each test, mass of the aluminum taken for each casting and weight percentage of silicon dioxide in grams.

Table: 3 required lengths and diameters for mechanical tastings

S.No	TEST	Diameter (mm)	Length (mm)
1	Tensile Test	16	100
2	Compression Test	16	45
3	Izod Test	16	80
4	Charpy Test	16	60
5	Hardness	16	25
Total		**16 mm**	**310**

For a single casting, the casted rods are produced with 16 mm diameter and 400 mm length by previously designed mould. So that preparing the specimens for the entire tests, the casting process is done for each percentage in once. Because, the total required length of the rod for all the tests are is 310 mm.

So that, from the bellow equation the mass of AL4032 required,

$$\text{Mass} = \text{Volume X Density}$$

Volume	=	$\frac{\pi}{4} D^2 X\ L$
Density	=	2700 Kg/M^3
Mass	=	$\frac{\pi}{4} 0.016^2 X\ 0.4$
Mass	=	0.21714 Kg or 217.14 Grams

Adding other allowances take mass of aluminium 4032 is 300 grams for each casting

Total aluminium required for all percentages of reinforcement and all tests is = 300 X 4 =1200 grams or 1.2 Kg

Similarly the required amount of silicon dioxide is,

- For 0 Wt% = (300 x 0)/100 = 0 Grams
- For 1 Wt% = (300 x 1)/100 = 3 Grams
- For 2 Wt% = (300 x2)/100 = 6 Grams
- For 3 Wt% = (300 x 3)/100 = 9 Grams

= 18 Grams

Therefore, total required silicon dioxide is = 18 Grams

IV. EXPERIMENTAL WORK

The stir casting method also known as liquid state technique is utilized for manufacturing of metal matrix composites. Here stir casting method is done with by using designed open hearth furnace. In this technique disseminate stage is assorted with molten metal with the help of motor stirrer. The liquid composite material is then cast by using traditional casting techniques (permanent mould casting).

Fig 8: Graphite crucible

Fig 9: open hearth furnace

The aluminum-silicon dioxide metal matrix composites are prepared by stir casting method. In the present work we have selected commercially pure aluminum- 4032 which is in solid form placed in the graphite crucible. The graphite crucible is placed in the muffle furnace and melted in the furnace up to 800^0c. Fortified material such as silicon dioxide is preheated to remove the moisture. Also 1 gram of Mg is added molten metal to remove wettability.

4.1. STIR CASTING PROCESS:

Initially took 300 grams of pure aluminum-4032 are melted up to liquefy point. Then by adding necessity quantity of reinforcement for 300 grams of pure aluminium-4032 is 3 grams for 1 Wt% and stirred continuously. Allow some time to obtain the super heat.

Fig 10: stirring

After the stirring molten metal with SiO_2 is poured in to the mould to form required shapes.

Fig 11: metal pouring

After pouring the molten metal in to the die allow some time to cool down or solidification.

Fig 12: fettling

Fettling the molded rods from the die

Fig 13: casted rods

The above steps followed for each percentage of reinforcement.

4.2. MACHINING OF COMPOSITES METAL:

As shown above specimens with necessitate volume and mass are produced. To obtain the form of specimen with necessary dimensions through ASTM standards, the specimen should be machined properly.

4.2.1. Machining of tensile specimens:

As shown in the above figures the tensile specimens are prepared according to ASTM standard E-8 that is sub size. Here tensile specimens are machined in required shapes by using CNC cutting machine.


Fig 14: CNC machine Fig 15: specimen for tensile test

4.2.2. Machining of compression test specimens:

As shown in the above figures the compression specimens are prepared according to ASTM standard E-9 that is medium with length 39mm, diameter 13mm and

L/D ratio is 3. Here compression specimens are machined in required shapes by using lathe machine.

Fig 17: specimens for compression test

4.2.3. Machining of charpy test specimens:

As shown in the above figures the charpy specimens are prepared according to ASTM standard E-23 that is v-notch with length 55 mm, width 10 mm, thickness 10 mm, notch depth 2 mm. Here charpy specimens are machined in required shapes by using shaper machine.

Fig 18: Specimen dimensions for charpy test

4.2.4. Machining of izod test specimens:

As shown in the above figures the izod specimens are prepared according to ASTM standard E-23 that is v-notch with length 75 mm, width 10 mm, thickness 10 mm, notch depth 2 mm. Here izod specimens are machined in required shapes by using shaper machine.

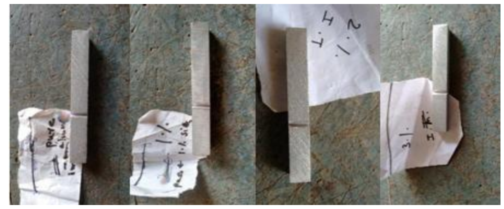


Fig 21: Specimen dimensions for Izod test

4.2.5. Machining of hardness test specimens:

As shown in the above figures the hardness specimens are prepared according to ASTM standard E18. Here hardness specimens are machined in required shapes by using shaper machine.

Fig 23: Specimens for hardness test

4.2.6. Samples preparation for microstructures:

Microstructures of the mixture were discern to disclose the distribution of SiO_2 nano particles in Al 4032. Specimens were polished on emery papers of different grades and then cloth polished with fine aluminum oxide powder on rotating disc. Microstructures are seen in unetched condition using optical microscope at 400X magnification.

Fig 24: Polished specimens for microscopic study

V. MECHANICAL PROPERTIES OBSERVATIONS

5.1. TENSILE TEST:

The tensile test was performed on a computerized universal testing machine in accordance with ASTM-E8 standards. Sub size sample with gauge length were utilized to assess ultimate tensile strength, percentage of elongation. The samples of various weight percentages are tested on universal testing machine to assess tensile strength. The following results are produced by testing samples are shown in table

2. From the table, it is obersved that unreinforced alloy has less tensile strength compared to evolved amalagamation. Also Al 4032 reinforced with SiO_2 at 1, 2 wt% has high tensile strength compared to Al 4032 reinforced with SiO_2 at 3 wt%. Reduction in tensile strength at 3 wt% is due to segregation effect.

Fig 26 : Tensile specimen in Universal testing machine and Broken specimens

5.2. COMPRESSION TEST:

The compression testing was carried out on a computerized universal testing machine in accordance with ASTM-E9 standards. Medium size sample with diameter 13mm, length 39mm and L/D ratio is 3 were utilized to assess compression strength. The samples of various weight percentages are tested on universal testing machine to assess compression strength. The following results are produced by testing samples are shown in table 3. From the table, it is obersved that unreinforced alloy has less compression strength compared to evolved amalgamation. Also Al 4032 reinforced with SiO_2 at 1, 2 wt% has high compression strength compared to Al 4032 reinforced with SiO_2 at 3% wt. Decrease in compression strength at 3 wt% is due to clustering and non uniform distribution of SiO_2 particles in Al 4032.

Fig 29: Compression specimen in universal testing machine and Broken specimens

5.3. IMPACT (CHARPY) TEST:

The charpy testing was carried out on a impact testing machine in accordance with ASTM-E23 standards. The samples of various weight percentages are tested on impact testing machine to assess impact strength. The following results are produced by testing samples are shown in table 3. From the below table, it is observed that gradual reduction in impact strength i.e charpy test by incorpation of SiO_2 particles of Al 4032 in various weight percentages. Because of incorpation of SiO_2 in various weight percentages with Al 4032, the brittleness of the material also increases. Due to its elevated brittleness the impact strength of the amalgamation decreases.

Fig 31 : Charpy impact testing machine and Broken specimens

5.4. IMPACT (IZOD) TEST:

The izod testing performed on a impact testing machine in accordance with ASTM-E23 standards. The samples of various weight percentages are tested on impact testing machine to assess impact strength. The following results are produced by testing samples are shown in table 4. From the below table, it is observed that gradual reduction in impact strength i.e izod test by incorpation of SiO_2 particles of Al 4032. Because of incorpation of SiO_2 in various weight percentages with Al 4032, the brittleness of the material also increases. Due to its elevated brittleness the impact strength of the amalgamation decreases.

Fig 34: Izod impact testing machine and Broken specimens

5.5. HARDNESS TEST (BRINELL HARDNESS TEST):

The hardness test carried on Brinell and Rockwell hardness testing apparatus. For conducting the hardness test follow the ASTM-E18 Standards. For evaluating the hardness of the all samples, taken 20 mm length and 15 mm diameter specimen. The tests are carried on 0, 1, 2 and 3 weight percentages of SiO2 sample.

Fig 37: Brinell hardness test machine and specimens

5.6. MICROSTRUCTURE CHARACTERIZATION:

The properties of the mixture depend on microstructure and interface peculiarity between strengthening and matrix. Below figures shows the microstructures of 1, 2, 3 wt% SiO_2 reinforced Al 4032.From microstructural examination, congregate and non- homogeneous dispensation of SiO_2 in Al 4032 were discerned. This is due to variation of contact time between SiO_2 particles in Al 4032. Porosities were perceived in all microstructures.

VI. RESULTS

Mechanical Properties:

To evaluate the mechanical properties like ultimate tensile strength, ultimate compressive load, impact strength and hardness test we performed some mechanical tests. These are, Tensile Test, Compression Test, Impact (IZOD-V) Test, Impact (CHRPY-V) Test and Hardness (Brinell) Tests.

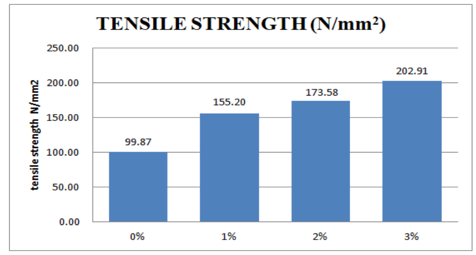
6.1. Tensile behavior of AL 4032-SiO_2

The tensile behavior of AL 4032-SiO_2 (0, 1, 2, and 3 Wt %.) is evaluated as cast and after ECAP. The ultimate tensile strength of Al 4032- reinforced with 0.5Wt% SiO_2 after ECAP is much higher than the before ECAP. Similarly, the ultimate breaking load is grater for AL 4032- reinforced with 0.25 Wt% SiO_2 after ECAP sample among the all samples.

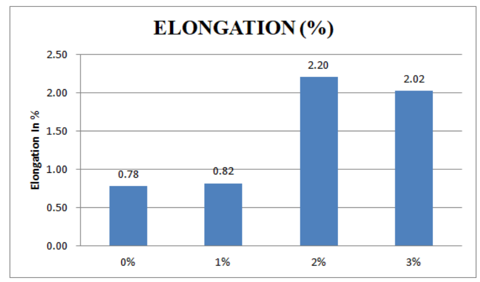
Table:4 Tensile Properties

COMPOSITION	TENSILE STRENGTH (N/mm^2)	ELONGATION %	YIELD STRESS (N/mm^2)
Al 4032+0% SiO_2	99.87	0.78	82.04
Al 4032+1% SiO_2	155.20	0.82	127.09
Al 4032+2% SiO_2	173.58	2.20	171.03
Al 4032+3% SiO_2	202.91	2.02	107.34

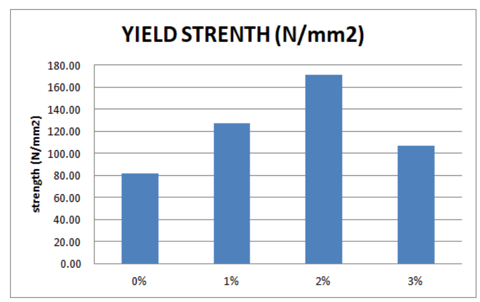
Based on the above tabulated results the tensile behavior of aluminium 4032 and silicon oxide Nano composite material is observed that the material is exposed ductility while increasing the weight parentage of silicon oxide i.e. the maximum values at 3 Wt%.



The maximum value of Ultimate Tensile Strength occurred at 3% of Sio_2



The maximum value of Elongation occurred at 2% of Sio_2



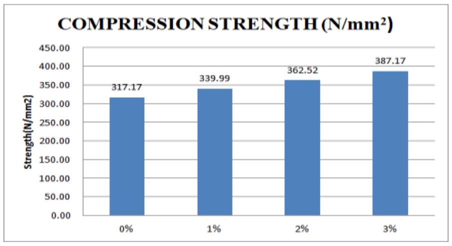
The maximum value of Yield Stress occurred after ECAP at 0.5%of Sio_2

6.2. Compressive behavior of AL 4032-SiO_2

The compressive behavior of AL 4032-SiO_2 (0, 1, 2 and 3 Wt. %.) were evaluated. The ultimate compressive load is maximum for AL 4032- reinforced with 2 Wt.% SiO_2.

Table:5 compressive Properties

COMPOSITION	ULTIMATE COMPRESSION LOAD (N)	ULTIMATE COMPRESSION STRENGTH (N/mm^2)
Al 4032+0% SiO_2	42096.80	317.17
Al 4032+1% SiO_2	45126.80	339.99
Al 4032+2% SiO_2	48116.40	362.52
Al 4032+3% SiO_2	51388.8	387.17



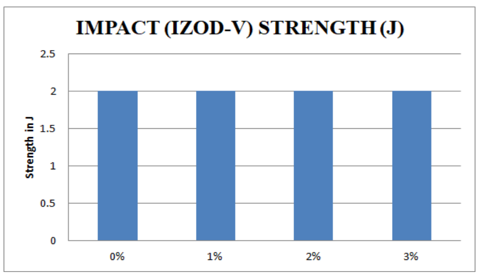
The maximum value of Ultimate Compression Strength occurred after ECAP at 0.5%of Sio_2

6.3. Impact strength of AL 4032-SiO_2

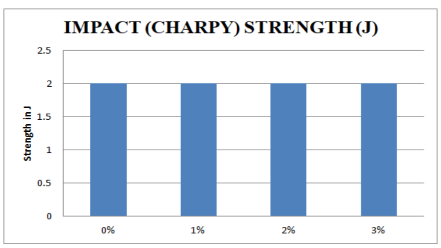
The impact strength of AL 4032-SiO_2 (0, 1, 2 and 3 Wt %.) were evaluated. In both the cases the breaking load is 2 joules.

Table:6 impact strength values.

Composition	IMPACT (IZOD-V) TEST IN JOULES	IMPACT (CHARPY) TEST IN JOULES
Al 4032+0% SiO_2	2	2
Al 4032+1% SiO_2	2	2
Al 4032+2% SiO_2	2	2
Al 4032+3% SiO_2	2	2



The value of Impact (Izod-V) occurred is same in all composition



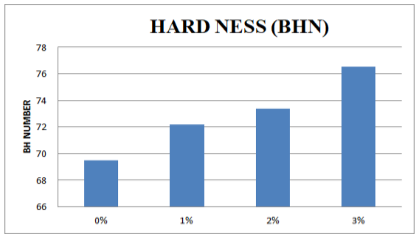
The maximum value of Impact (Charpy) occurred is same in all composition

6.4. Hardness (Brinell) test of AL 4032-SiO_2

The hardness of the AL 4032-SiO_2 (0, 1, 2, and 3 Wt %.) were evaluated as. The Brinell hardness number (HB) is maximum for AL 4032- reinforced with 3 Wt% SiO_2.

Table:7 hardness values

Composition	HARD NESS TEST(BHN)
Al 4032+0% SiO_2	69.5183
Al 4032+1% SiO_2	72.1847
Al 4032+2% SiO_2	73.3967
Al 4032+3% SiO_2	76.5277



The maximum value of Hardness occurred at 3%of Sio_2

6.5. Microstructure Characterization:

The properties of the mixture depend on microstructure and interface peculiarity between strengthening and matrix. Below figures shows the microstructures of 1, 2, 3 wt% SiO_2 reinforced Al 4032.From micro structural examination, congregate and non- homogeneous dispensation of SiO_2 in Al 4032 were discerned. This is due to variation of contact time between SiO_2 particles in Al 4032. Porosities were perceived in all microstructures.

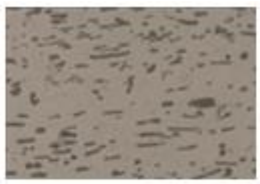


Fig 40: Microstructure of Al 4032

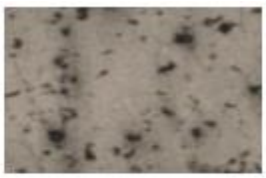


Fig 41: Microstructure of 1 wt%SiO_2 Reinforced Al 4032

Fig 42: Microstructure wt% SiO_2

Fig 43: Microstructure of of 2 3 wt% SiO_2

VII. CONCLUSION

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

- Addition of SiO_2 in Al 4032 improves the tensile strength compared to unreinforced composites. Also Al 4032 reinforced with SiO_2 at 1, 2 wt% has high tensile strength compared to Al 4032 reinforced with SiO_2 at 3% wt.
- Addition of SiO_2 in Al 4032 improves the compression strength compared to unreinforced composites. Also Al 4032 reinforced with SiO_2 at 1, 2 wt% has high compression strength compared to Al 4032 reinforced with SiO_2 at 3% wt.
- Addition of SiO_2 in Al 4032 improves the Rockwell and Vickers hardness compared to unreinforced composites. Also Al 4032 reinforced with SiO_2 at 1, 2 wt% has Rockwell and Vickers hardness compared to Al 4032 reinforced with SiO_2 at 3% wt.
- Addition of SiO_2 in Al 4032 there is no change in the impact strength viz., izod, charpy compared to unreinforced composites.
- Agglomeration and non uniform distribution of SiO_2 particles in Al 4032 were perceived in the microstructure at 3wt%.

From the above results, the SiO_2 reinforced Al 4032 has better tensile strength, compression strength and hardness than unreinforced alloy.

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