International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 5 May 2023, pp: 947-955 www.ijaem.net ISSN: 2395-5252

Study of Mechanical Properties of Al6065 with CNT

[1] MadhusudanaH C,[2]Nikhil N, [3] Sahil M, [4] Nandish S N, [5] Srinivas S Bharadwaj
[1]*Assistant Professor*[2,3,4,5]*Students, Department of Mechanical Engineering, RNS Institute of Technology, Channasandra, Bengaluru, Karnataka, India*

Date of Submission: 15-05-2023 Date of Acceptance: 30-05-2023

ABSTRACT:In the past few decades, the research in material science has been primarily focused on composites as they can be developed into light weight, environmentally friendly, and high-performance appliances. Aluminium is lightweight, possesses good tensile strength, fatigue strength, has good machinability and is also wear resistant. These characteristics make it an ideal candidate for its use in automotive and aerospace industries. In the proposed paper, Multiwalled Carbon Nanotube (MWCNT) coated with surfactants Sodium dodecyl Sulphate (SDS) and Triton-X-100 are used as reinforcement with Al6065.The mechanical properties such as Impact, Hardness and SEM Analysis is studied after synthesizing of Metal matrix composite using Bottom pour Stir Casting process.

KEYWORDS: Al6065, Carbon Nanotubes (CNT), Metal Matrix Composite (MMC), Stir Casting, Impact Test, Hardness Test, SEM Test.

I. INTRODUCTION

With expanding motor sector carbon emissions have increased to a greater extent. Reducing these harmful pollutants is a challenge to the engineers and researchers. One such possibility available to overcome this shortfall is by Building lighter cars which drastically cut down on the fuel usage as they require less fuel to operate. Most effective solution to reduce weight turned out to be making chassis from Ultra High Strength Steel (UHSS). Elevated temperatures are necessary to manufacture UHSS, and thus aluminium played a pivotal role in the development as it is light weight, possesses good tensile strength, has good machinability and is also wear resistant. Although aluminium offers a phenomenal strength-to-weight ratio, it is less strong than other metals when considering only strength. As a result, aluminium is frequently alloyed in various ratios with other metals to enhance its qualities. Magnesium and silicon serve as the primary alloying elements in aluminium of the 6xxx series. The 6xxx series of aluminium alloys have a relatively high strength and are heat treatable, adaptable, weldable, highly formable, and highly corrosion resistant. Aluminium alloy 6065 is part of the 6000 series.

Since composites may be developed into lightweight, eco-friendly, high-performance appliances and as they are much stiffer and stronger than traditional materials, they have been of primary focus. One allotropic form of carbon, known as carbon nanotubes (CNT), has several distinctive mechanical and physical characteristics and lowdensity properties that make them a good reinforcement material for many kinds of composites. A carbon nanotube (CNT) is a tube made of carbon with diameters typically measured in nanometers.They canalso bereferredto hastubeswithanundeterminedcarbon-wall structure and diameters less than 100 nanometers. Single-Walled Carbon Nanotubes (SWNTs) and Multi-Walled Carbon Nanotubes (MWNTs) are the two main varieties of carbon nanotubes. One type of carbon allotrope, single-wall carbon nanotubes (SWCNTs), are nanometer-sized tubes that are midway between fullerene cages and flat graphene. Single-wall carbon nanotubes are nested inside of multi-wall carbon nanotubes (MWCNTs), which have a ring-like structure and are only loosely connected by van der Waals interactions. These tubes are extremely similar, if not identical, to the long straight and parallel carbon layers cylindrically stacked around a hollow tube proposed by Oberlin, Endo, and Koyama. CNT reinforcement increases strength without significantly increasing weight. Numerous polymer matrix composites (PMCs) and metal matrix composites (MMCs) containing base metals like aluminium, magnesium, copper, etc. have been

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created and tested with CNT as one of their reinforcing agents.

A composite material having fibres or particles scattered in a metallic matrix, such as copper, aluminium, or steel, is known as Metal Matrix Composite (MMC) in the field of materials science. Usually, the secondary phase is a metal, such as steel, or a ceramic, like alumina or silicon carbide. They are often divided into three categories based on the kind of reinforcement: short continuous fibres, particles, or short discontinuous fibres (whiskers). A hybrid composite is one that has at least three different components. MMCs are frequently employed in demanding applications because they can have substantially better strength-to-weight ratios, stiffness, and ductility than conventional materials. Due to their usually weaker thermal, electrical, and radiation resistance, MMCs are normally only used in the most extreme conditions. Three categories of MMC production exist: solid, liquid, and vapour.

Solid State Methods:
i) Powder Blending & Consolidation (Powder Metallurgy)
ii) Foil Diffusion Bonding

Liquid State Methods:
i) Electroplating & Electroforming
ii) Stir Casting
iii) Pressure Infiltration
iv) Squeeze Casting
v) Spray Deposition
vi) Reactive Processing

Semi-Solid Methods:
i) Semi- Solid Powder Processing

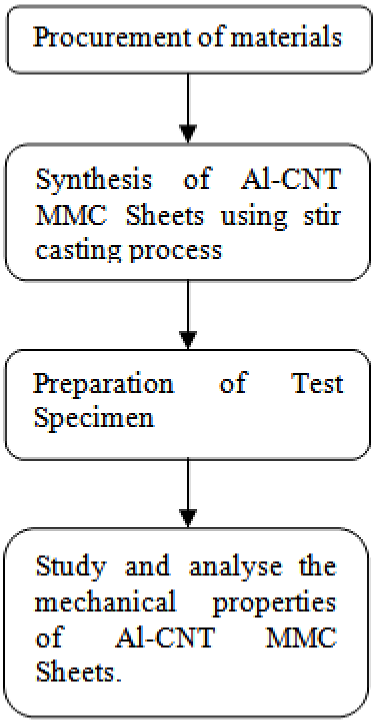
Vapor Deposition:
i) Physical Vapor Deposition

The mechanical properties are studied by conducting Impact Test, Hardness Test and Scanning Electron Microscope (SEM) Test. Impact tests are performed to examine a material's tensile strength. The capacity of a substance to absorb energy during plastic deformation determines its toughness. Temperature can also affect a material's impact value. In general, a material's impact energy decreases as temperature drops. The Izod impact test's value may also be influenced by the specimen's size since it may allow for a varied amount of material flaws that might function as stress risers and reduce the impact energy. In impact testing, Charpy and Izod Specimen setups are most frequently used. Charpy Impact Tests are performed using instrumented equipment that can measure loads between 1and300 foot pounds at temperatures between -320°F and over 2000°F. The Izod Impact Strength Test is similar to the Charpy Impact test. This test is an ASTM-required procedure for evaluating a material's impact resistance. A pivoting arm is raised to a predetermined height (constant potential energy), then released. The amount of energy absorbed by the sample is calculated based on the height the arm swings to after striking it. A sample with notches is frequently used to determine impact energy and notch sensitivity.

The three fundamental methods for evaluating hardness are scratch, indentation, and rebound measurements. A sample's resistance to fracture or long-term plastic deformation brought on by contact with a sharp item is measured by its scratch hardness. It is a general rule that something made of a harder material will scuff something made of a softer material. When assessing coatings, the force necessary to pierce the film and reach the substrate is referred to as the scratch hardness. The Mohs scale is the most often used test in mineralogy. One tool that can be used to measure this is the sclerometer. Another piece of equipment used for these tests is the pocket hardness tester. The resistance of a sample to material deformation brought on by a continual compressive stress from a sharp item is measured by indentation hardness. Engineering and metallurgy are the two main fields that employ indentation hardness tests. The tests function on the fundamental tenet of assessing the crucial dimensions of an indentation made by an indenter that has been properly sized and loaded. Among others, Rockwell, Vickers, Shore, and Brinell are common indentation hardness scales. Rebound hardness, sometimes referred to as dynamic hardness, gauges how high a diamond-tipped hammer will "bounce" off of a material after being dropped from a certain height.A scleroscope is the tool used to take this measurement. Using the Ultrasonic Contact Impedance (UCI) technique, the frequency of an oscillating rod is used to calculate hardness.

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The sample's surface topography and chemical composition are revealed by the signals that are created as a result of the electrons' interactions with the sample's atoms. Specimens are examined at a variety of cryogenic or high temperatures using specialised equipment. To fit on the specimen stage, SEM samples must be tiny enough, and they may require additional processing to improvetheir electrical conductivity and stabilise them so they canresist the high vacuum conditions and high energy beam of electrons.

II. METHODOLOGY FLOWCHART



III. CALCULATIONS AND DESIGN

i) **Calculations for Aluminium:**

1. Volume V1 = 250 × 56 × 2.5 = 35,000mm^3
2. Volume V2 = 250 × 56 × 2.5 = 35,000mm^3
3. Volume V3 = 250 × 8 × 6 =12,000mm^3

Total Volume V = 35000mm^3 + 35000mm^3 + 12000mm^3
= 82000mm^3

Mass = Density × Volume
Mass = 0.00272 $\frac{gms}{mm^3}$ × 82000 mm^3
= 223.04 gms

As there will be some amount of wastage during the casting process, 226.96gms of aluminium is added to compensate for this wastage.

□ Mass = $223.04gms + 226.96gms$
= 450gms

Therefore, 450 grams of aluminium is required for a sheet of dimension 250mm × 120mm × 2.5mm

ii) **Calculations for Carbon Nanotube:**

1) Specimen 1: 0.5% of CNT added to 450gms of Al6065

$$CNT1 = \frac{0.5}{100} \times 450 = 2.25gms$$

2) Specimen 2: 1% of CNT added to 450gms of Al6065

$$CNT2 = \frac{1}{100} \times 450 = 4.5gms$$

3) Specimen 3: 1.5% of CNT added to 450gms of Al6065

$$CNT3 = \frac{1.5}{100} \times 450 = 6.75gms$$

4) Specimen 4: 2% of CNT added to 450gms of Al6065

$$CNT4 = \frac{2}{100} \times 450 = 9gms$$

iii) **Die Part:**

The image of the Die Partobtained to make the specimen is as shown in the figure i.

Fig i: Mild Steel Die used to make the specimen

IV. STIR CASTING

i) Preparation of Aluminium for casting: The aluminium ingots were cut into pieces weighing 450gms as determined by the calculations for the dimensions of the die.

ii) Bottom Pour Stir Casting: For the creation of particle reinforced metal matrix composites (PMMC), stir casting is typically used. It is a fundamental step in the creation of composites to swirl the reinforcing ingredient material into the molten metal.

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Fig ii. Bottom pour stir casting equipment at V.V.C.E at Mysore.

The casting method that was used is Bottom Pour Stir Casting and the process was carried out at Vidyavardhaka College of Engineering (VVCE), Mysore.This college was specifically chosen because it has bottom pour casting technology as shown in the figure ii. After being removed from the stir casting machine, aluminium quickly cools down, making it challenging to pour the melt into the die and producing significant waste. Bottom pour stir casting machines are useful because the melt can be poured straight from the crucible into the die, avoiding this arduous cooling process and considerable wastage.

V. PREPARATION OF AL - CNT MMC SHEETS

The following steps were involved in the casting of Al-CNT mmc sheets:

1. Applying non-stick graphite-based coating to the die: A high-temperature graphite based nonstick coating is applied to the die. This prevents the adhesion of molten aluminium onto the walls of the die while cooling and helps in the formation of sheets without any voids on the surface.

2. Melting the aluminium ingots in a high temperature furnace: Aluminium ingots are placed in the crucible depicted in Figure iii, and after that, they are heated up in a furnace. The furnace is adjusted to a temperature of roughly 800˚C. The aluminium ingots and the crucible are left within the furnace to melt correctly.

Fig iii. Melting the aluminium ingots in high temperature crucible.

3. Pre-heating of the Die: The die is simultaneously pre-heated to a temperature of 630° C. This aids in the melt's uniform settling and the slowing down of the melt's quick cooling once it is poured into the die.

4. Addition of De-gasifier: Due to the tremendous reactivity of molten aluminium, when it comes into touch with damp materials or wet hands, the water breaks down and releases hydrogen into the melt. The mechanical qualities of the finished aluminium castings are adversely affected by high concentrations of this dissolved gas. As a de-gasifier, hexachloroethane C_2Cl_6,was employed. For every 100 gm of aluminium, 1 gram of hexachloroethane is added. After adding the de-gasifier, it is stirred at a constant speed using a mechanical stirrer. This facilitates the de-gasifier's even distribution throughout the melt.
5. Removal of slag: Slag is produced when de-gasifier is incorporated into the melt. As can be seen in figure iv, slag is a by-product created during the melting of aluminium that, if not removed, can cause a decrease in the mechanical characteristics of the metal.

Fig iv. Slag formed during the melting process.

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6. Addition of CNT: Incorporated within the melt is carbon nano tube powder. Aluminium foil is used to add the appropriate amounts of CNT powder to the furnace. Aluminium foil is used to assist avoid spills and consequent CNT powder waste.

7. Stirring of Al + CNT using mechanical stirrer: The mechanical stirrer is turned ON and the melt is swirled at a constant speed of roughly 800 rpm once the aluminium foil has completely dissolved into the melt. This aids in the powder's even dispersion throughout the melt.

8. Pouring of melt into the die: An opening is made at the bottom of the casting machine after the CNT powder has been given time to dissolve into the melt. The melt is sent into the die by this aperture. The melt is given full reign to pour into the die. The opening is sealed after the crucible has been empty, and the machine is turned OFF.

9. Cooling of die & extraction of sheets: The die is allowed to cool in the presence of atmospheric air once the melt has been completely poured into it. The sheets are extracted to obtain the Al-CNT metal matrix composite sheets when the die has completely cooled.

Using the bottom pour stir casting equipment, the following specimens of Al-CNT metal matrix sheets were produced:

a. 100% pure aluminium 6065 sheets.

b. 99.5% aluminium 6065 - 0.5% CNT, metal matrix composite sheets.

c. 99% aluminium 6065 - 1% CNT, MMC sheets.

d. 98.5% aluminium 6065 - 1.5% CNT, MMC sheets.

e. 98% aluminium 6065 – 2% CNT,MMC sheets.

VI. TESTS AND RESULTS

i) Izod Impact Test:

The steps involved in the Izod Impact test are as follows:

a. Preparation of specimen: The specimens are prepared for the Izod Impact test by marking on it as shown in figure v, to make a notch to improve the crack propagation after impact.The notch also prevents deformation of the specimen upon impact. A 'V' shaped notch is provided on the specimen using a specialized Notch Cutting machine.

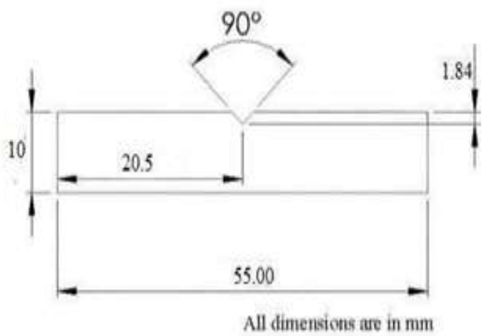

Fig v. Drawing of the notch measurements to be made on the specimen

b. Izod Impact Test: As illustrated in figure vi, the specimen is set up in the holder in a cantilever position. The specimen is then struck by a striker on the pendulum's arm, which breaks it as depicted in figure vii. The energy that the specimen used to break itself is observed and computed for the calculations.

Fig vi. Notched specimen set up in the holder.

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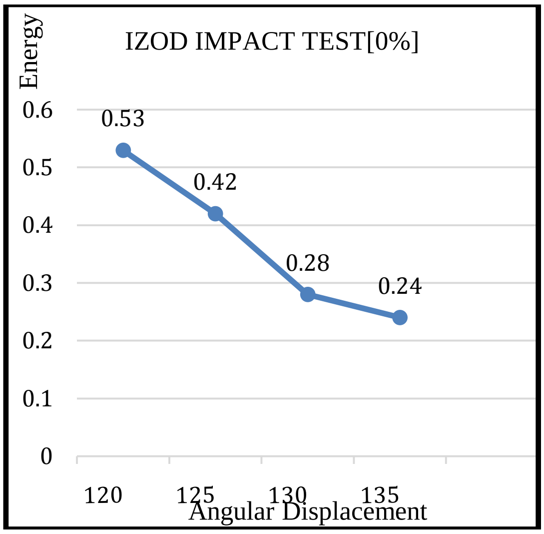
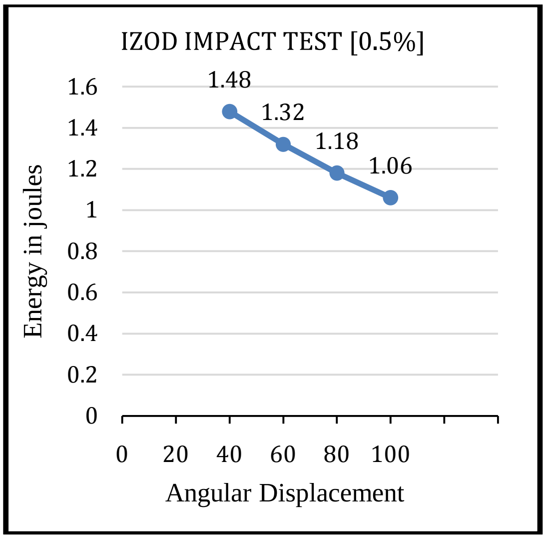
Fig vii. The sample piece broken inside of the holder.

Izod Impact Test Results:
1. Izod impact test result for 0.5% CNT specimen:



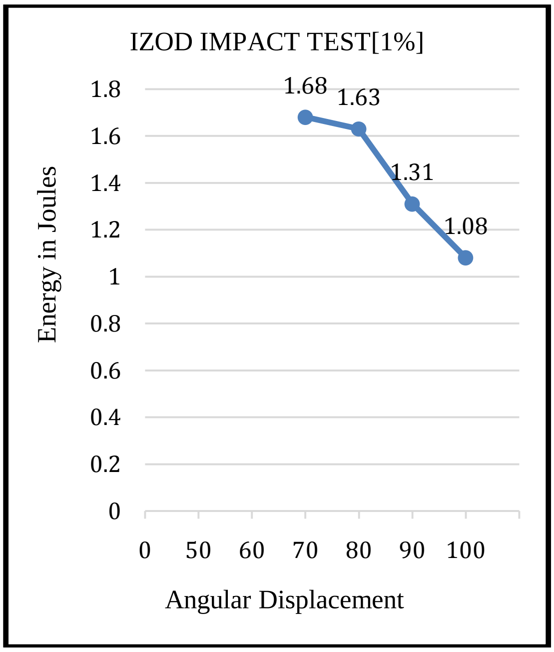
Result:
Izod Impact Energy: 0.53J
Izod Impact Strength: 212 J/m

2. Izod impact test result for 0.5% CNT specimen:



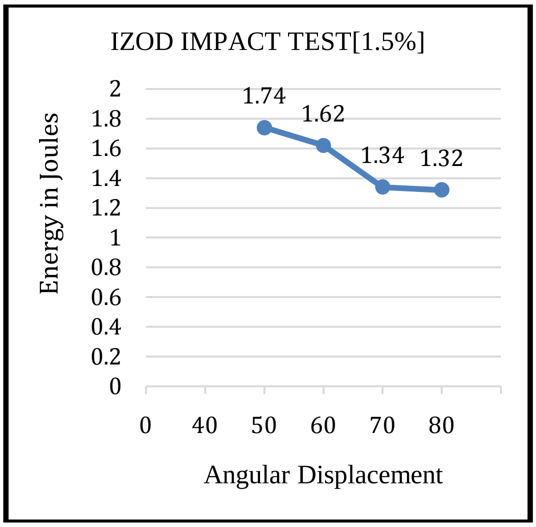
Result:
Izod Impact Energy: 1.48J
Izod Impact Strength: 592 J/m

3. Izod impact test result for 1% CNT specimen:



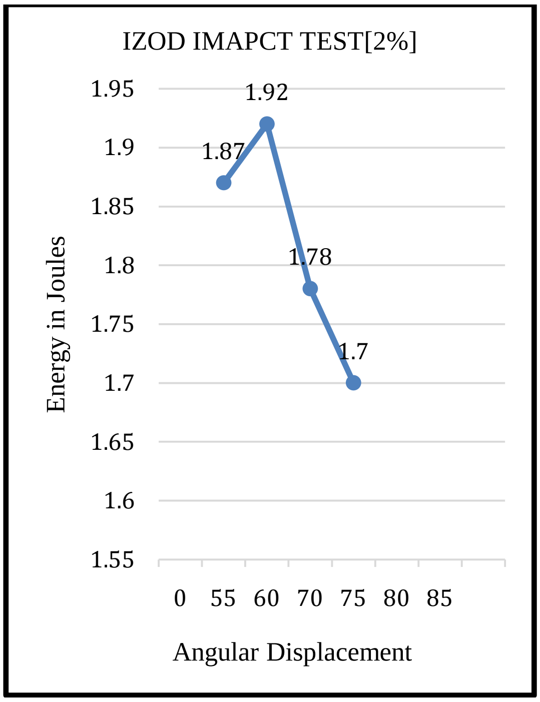
Result:
Izod Impact Energy: 1.68J
Izod Impact Strength: 672 J/m

4. Izod impact test result for 1.5% CNT specimen:



Result:
Izod Impact Energy: 1.74J
Izod Impact Strength: 696 J/m

5. Izod impact test result for 2% CNT specimen:



Result:
Izod Impact Energy: 1.92J
Izod Impact Strength: 768 J/m

Overall Result:

CNT content (wt. %)	Izod Impact Energy (joules)
0.00%	0.53
0.50%	1.48
1.00%	1.68
1.50%	1.74
2.00%	1.92

ii) Hardness Test:
BarcolImpressorshown in figure viii, is used to find the hardness of the specimen.

Fig viii. BarcolImpressor being used to test the hardness.

The following table shows the readings of the Vickers harness test.

CNT Content (wt. %)	Reading 1	Reading 2	Reading 3	Average
0.00%	33.9	37.1	40.1	37.03
1.00%	40.5	42.7	39.6	40.93
1.50%	38.3	43.5	42.7	41.5
2.00%	43.9	42.1	49.3	45.1

iii) SEM Analysis:
Various samples were used to prove the presence of CNT in the Specimen under different

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magnification lens.The analysis was carried out at Dextrose. The following images ix, x and xi depict the SEM analysis results undermagnification of 100µm, 50µm and 30µm respectively

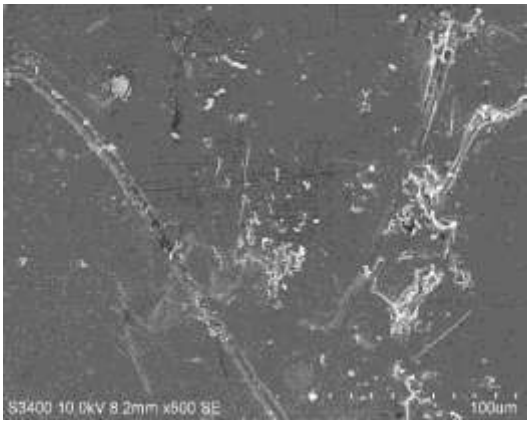

Fig ix. SEM analysis Result for 100µm

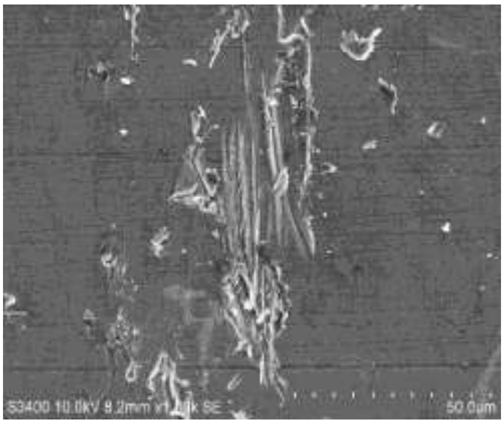

Fig x.SEM analysis Result for 50µm

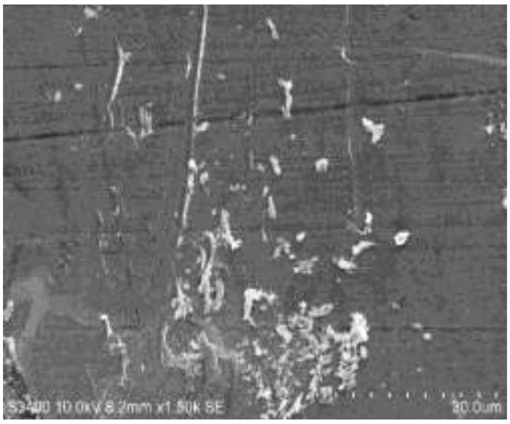

Fig xi.SEM analysis Result for 30µm

VII. CONCLUSION

Improvements to the mechanical characteristics of metal matrix composites enhanced by carbon nanotubes, such as impact strength and hardness, have undergone extensive analysis.

Bottom Pour Stir Casting experiments and data from a literature review led researchers to the conclusion that MWCNT dispersion is essential for high composite strength. MWCNT tends to float on the surface rather than mix evenly because it is less dense than Al 6065. Coating CNT with SDS and Triton -X -100 will prevent this from happening.

According to the findings, Al-MWCNT metal matrix composites have a higher Impact Strength than pure Al 6065. In addition, pure Al 6065 is less hard than composites made of Al-MWCNT metal matrix. The mechanical characteristics of the composite improve together with the MWCNT content.

Achieving uniform CNT dispersion through surface modification and creating novel casting techniques for metal matrix composites are further hurdles.

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