# Investigation on mechanical properties of reinforced glass fibre/epoxy with hybrid nano composites

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In this study the experimental investigation of mechanical behaviour of Multi-Walled Carbon nanotubes (MWCNTs) and Aluminium Oxide ($Al_2O_3$) reinforced with E-Glass/Epoxy nanocomposites at 0.5%, 1.5% and 2.0% of weight rated with 225 GSM, 300 GSM and 450 GSM glass fibres were studied. Test specimens were prepared at the standardof ASTM D638 for tensile specimen ASTM D256 for impact specimen. Testspecimens were prepared at the ratio of MWCNTs: $Al_2O_3$ is 1:4. 1.5 wt. % of Multi-Walled CNTs filledE-Glass/Epoxy nanocomposites showed improved mechanical properties than glass fiber reinforced epoxy composites.450 GSM reinforced glass fiber epoxy composites containing 1.5wt. % of MWCNTs improved 36.27 % of higher tensile value and 28.57 % of impact value than the glass fibre reinforced epoxy composites. 225 and 300 GSM reinforced glass fibre epoxy composites with 1.5 wt. % of MWCNTs composites also has improved tensile and impact value than glass fibre reinforced epoxy composites. But, overall 450 GSM reinforced fibre nanocomposites showed enhanced mechanical properties than the other GSM reinforced nanocomposites. This proves Multi-Walled Carbon Nanotubes is a successful reinforcement for E-Glass/Epoxy matrix and it improves its properties and performance.

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*Keywords:* E-Glass fibre, MWCNTs, Alumina

## 1. Introduction

Composite materials application has been a trend due to its load sustaining capacity in various engineering applications under different atmospheric conditions. Polymer matrix composite is one of the major composite type having wide applications. E-glass/epoxy is one of the versatile types of composite based on its flexible production technique. The scope of creating polymer Nanocomposites is to propel the mechanical properties to get together the modern requirements. The fields, for example, aviation, marine, sports require high elasticity, adaptability and high wear which is given by these materials.

K.Devendra et al [1]. Investigated the on the mechanical properties of E-glass fiber reinforced epoxy composites filled by various filler materials. From the results, it is observed that increase in addition of $Al_2O_3$ and MWCNTs to composites increases the hardness of the composite. D.Harsha Vardhan et al [2]. Investigated the composite material significantly provide highly impressive resulting material that provide highly strength, stiffness and good energy absorbing characteristics. From the result Carbon fillers improves the strength like Tensile, impact & flexural properties. Ritishhoda et al [3], Abhijith Vaidya S et al [4], Myung-GonKim, Bum Moon et al [5], studied about the mechanical properties important parameters have to be improved to meet the high requirements by adding hybrid ceramics. In this work the results suggest that CNTs are used as an alternative filler to enhance resistance. But now, CNTs are combined with epoxy resins to increase the tensile strength and good bonding. Before applying CNTs, amino-

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fictionalization process is conducted to enhance the bonding between CNTs and epoxy resin. Amino fictionalization makes reactive groups On CNTs surface to form bonds between CNTs and epoxies. An environmental test chamber is used to stimulate a cryogenic environment and test procedure is carried on to, obtain high fracture toughness. The variation in the toughness by CNT addition is investigated through DCB test. Finally the functionalized CNT-epoxy specimen shows higher tensile strength than as received specimen.

In this work [6-10] the effect of the Carbon Nano Tubes (CNT) at enhanced transverse tensile property between carbon fibers and epoxy matrix. When the multi walled CNT content equals 0.5wt %, transverse tensile strength shows a similar tendency as the contact angle. The transverse tensile strength is increased respectively by 29.3% and 51.7% at room temperature and 77K at the 0.5% of CNT content compared to pure epoxy composites. When the content compared to pure epoxy composites. When the content of the MWCNTs is further increased to 1.0wt%, the viscosity of the CNT/Epoxy mixture will be dramatically increased. But the transverse tensile strength is then decreased cause the stress concentration in the Nano composites.

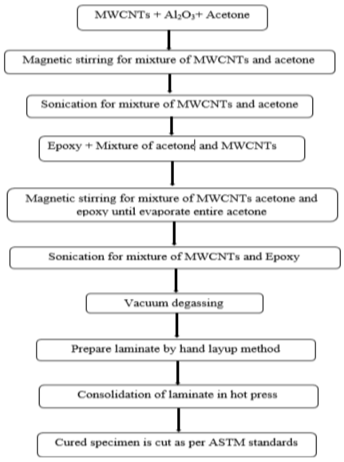


*Fig. 1.Methodology.*

## 2. MWCNTs

Carbon Nanotubes are produced by the closed controlled CVD method. This product is suitable as reinforcement filler in base polymers for the fabrication Nano-composites/bio-Nano-composite. MWCNTs are in available form black powder and characterization method is visual. It has approximate diameter of 10 nm and length is 6-9 microns. It has greater than 98 % of nanotubes purity and less than 1 % of metal particles. Specific area of MWCNTs is 250-300 $m^2$/g. Bulk density of MWCNTs is 0.10-0.06 g/$cm^3$.


*Fig. 2.MWCNTs (10 gm pack).*

MWCNTs 10 gm package were brought from IENT Incorporation, Erode.

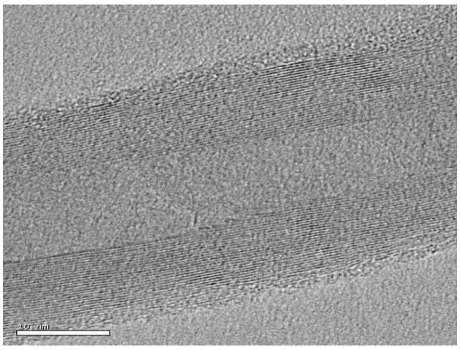

*Fig. 3.* Transmission electron microscopy image of MWCNTs *(TEM).*

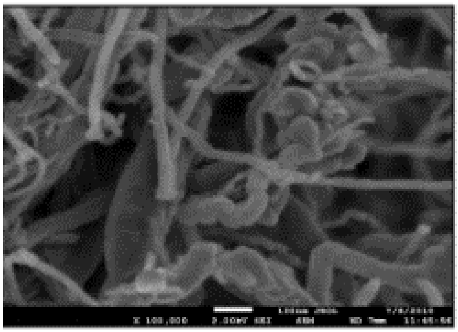

*Fig. 4.* Scanning Electron Microscopy image of MWCNTs (SEM)

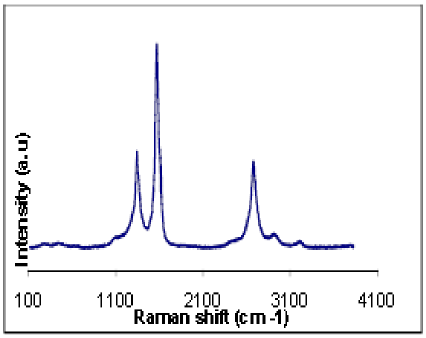


*Fig. 5.Raman Spectrum Analysis of* MWCNTs.

*Table 1.Properties of Multi Walled Carbon Nanotubes.*

| S.NO | MWCNT | DESCRIPTION | CHARACTERIZATION METHOD |
|---|---|---|---|
| 1 | Production method | Chemical Vapor Deposition[CVD] | Closed controlled |
| 2 | Available form | Black powder | Visual |
| 3 | Diameter | -10 nm | SEM, TEM |
| 4 | Length | 6-9 micron | SEM, TEM |
| 5 | Purity | >98% | TGA, RAMAN |
| 6 | Metal particles | <1% | ICP-MS |
| 7 | Amorphous carbon | <1% | HRTEM |
| 8 | Specific surface area | 250-300 $m^2/g$ | BET |
| 9 | Bulk density | 0.10-0.06 $g/cm^3$ | pycnometer |

From Fig.3 TEM image showing MWNTs product with typical one dimensional Structure of 10 to 15 nm dia. From Fig. 4 SEM image showing MWCNTs product with typical one dimensional entangled structure 6-9 micron.From Fig. 5 Raman spectrum of MWNTs Powder showing a strong G band and a low D/G ratio confirming the pristine nature of these products. The 2D band shape at ca. 2700cm-1 also confirms the absence of graphite.

From Table 1 specification and description of MWCNTs were studied and tabulated.

## 3. Nano aluminium oxide

$Al_2O_3$ powder has wide range of applications such as electronic ceramics, high strength materials and catalysts. It is also called as NANO ALUMINA. Nano aluminiumoxide are in available form white powder and characterization method is visual. It has average particle size of 50-200 nm (SEM). Crystalline phase of Nano $Al_2O_3$is alpha (PXRD). Crystallite size of Nano alumina is 10-20 nm. It has greater than 99 % of purity and less than 0.5 % of metal particles. pH value is 7.9 and bulk density is 0.2-0.4g/cm$^3$.

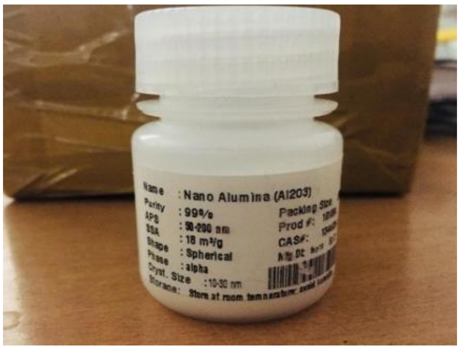


*Fig. 6. Nano Alumina powder (10 gm pack).*

Nano Alumina powder of 10 gm package were bought from Sri Sai Scientific Company, Coimbatore.

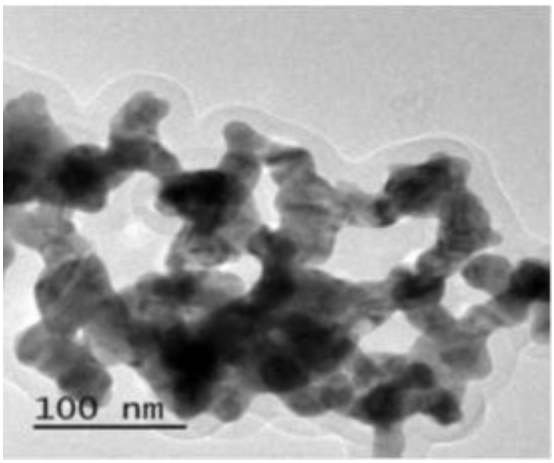


*Fig. 7.* Transmission Electron Microscopy image of $Al_2O_3$ *(TEM).*

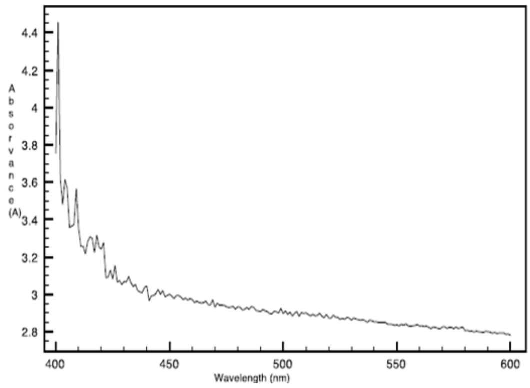


*Fig. 8. UV Spectrum analysis of* $Al_2O_3$

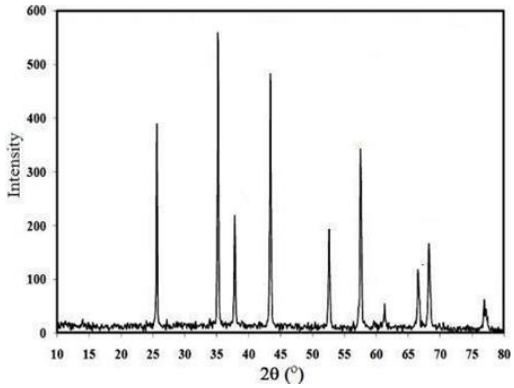


*Fig. 9. X-Ray Diffraction (XRD) image of* $Al_2O_3$

From Fig. 7 TEM image showing Nano alumina product with typical one dimensional Structure of 10 to 20 nm crystallite size. From Fig. 8 UV Spectrum it shows the mean aggregate size and Al content in the Nano alumina powder. From fig. 9 X-Ray Diffraction is a powerful non-destructive technique for characterizing crystalline materials. It shows the crystal structure and crystallite size is 10-20 nm.

*Table 2.Properties of Aluminum Oxide Nano powder.*

| Product Name | Nano Alumina or Aluminum Oxide |
|---|---|
| Molecular Weight | 101.96 |
| Color and Form | White Powder |
| Specific Surface Area (BET) | $\geq$550 $m^2$/g |
| True Density | 2.9 g/cc |
| Crystallite Size | 10-20 nm |
| Mean Aggregate Size | 5μm |
| Average Pore Diameter | 110Å |
| Total Pore Volume | $\geq$1.5 cc/g |
| Moisture Content | $\leq$12% |
| Bulk Density | 0.20 g/cc |
| Al Content (Based on Metal) | >99.2% |

## 4. Mechanical dispersion of MWCNTs

Mechanical dispersion of multi walled carbon Nanotubes is carried out using ultrasonic wave mixer without any of chemical surfactants. The good thing about ultrasonic wave mixer is it can break the Van Der Waals forces between the CNTs and detach them in the aqueous solutions. The ultrasonic wave mixer induces high energy into the solution with high frequency vibrations, causing vacuum bubbles i.e., micro and Nano cavitation's to be formed among the solution molecules.These micro and Nano vacuum bubbles will detonate when they touch the CNT surfaces. The detonate bubbles will cause a massive vacuuming force that will pull out the Nanotubes away into the solution. Hence, the CNTs will be separated from each other and in used in the solution, the suspended CNTs will start to agglomerate and bundle again. In order to disperse the CNTs effectively, adequate energy and sonication time should be applied. If excessive amounts of sonication energy, sonication time and both are introduced into the CNT solution, the huge forces from detonate micro bubbles will fracture the Nanotubes. Optimizing the sonication process will require the optimum combination of sonication energy, duration, volume of solution, concentration of Nanotubes, temperature, amount, and type of chemical surfactant like anionic, cationic and non-ionic used in the solution.

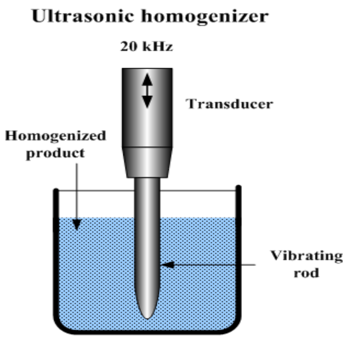


*Fig. 10.Ultrasonic Homogeniser.*

## 5. Die preparation and curing of epoxy

Die is prepared as per the ASTM standards for tensile, impact tests. The die is cleaned thoroughly before filling the reinforced glass fibre with MWCNT/epoxy solution, mold release agent is used for easy removal of test specimen after curing. The die is placed in a horizontal surface with good surface and grease is applied around the die for resisting the solution from leaking out. The ASTM standard used and number of specimens taken where listed in the table below.

*Table 3.Testing specimens.*

| S.NO | ASTM STANDARD OF SPECIMEN | TESTING TO BE DONE | NUMBER OF SPECIMEN |
|---|---|---|---|
| 1 | ASTM D638 | TENSILE TEST | 12 |
| 2 | ASTM D256 | IMPACT TEST | 12 |

*Fig. 11. ASTM D638 & ASTM D256.*

ASTM's physical and mechanical testing standards provide guides for the proper procedures employed in the determination of the physical, mechanical and metallographic properties of certain materials, particularly metals and alloys. Using test methods such as scanning electron microscopy, hole-drilling strain-gage method, semiautomatic and automatic image analysis, and X-ray diffraction, parameters like elastic moduli, impact strength, ductility, hardness, residual stress and grain size are measured.

### 5.1. Test Specimen images

Test specimens were fabricated for Tensile and impact test as per the ASTM Standard. Figure 12 shows the Tensile and impact samples of pure Epoxy and E-fibre. Figure 13, 14, 15, shows the Tensile and impact samples of pure Epoxy and E-fibre.with 1.0, 1.5, 2.0 wt % of MWCNT & $Al_2O_3$) respectively.


*Fig. 12. Tensile and impact samples of pure Epoxy and E-fibre.*

*Fig. 13 Tensile and impact samples of pure Epoxy and E-fibre.with 1.0 wt % of MWCNT & $Al_2O_3$).*

*Fig. 14 Tensile and impact samples of pure Epoxy and E-fibre.with 1.5 wt % of MWCNT & $Al_2O_3$).*

*Fig. 15 Tensile and impact samples of pure Epoxy and E-fibre.with 2.0 wt % of MWCNT & $Al_2O_3$).*

## 6. Analysis of mechanical properties of MWCNTs polymer

**Tensile Test:** Tensile test was performed using Universal Testing Machine (UTM). Each specimen was measured with calipers to determine the area of cross section. The load cell was zeroed to ensure that the software only measured the tensile load applied to the specimen. The specimen was loaded into the jaws of the instron load frame. The maximum force of the machine is 600 kN. The gauge length of the specimen is 50 mm. The peak load applied to each specimen is 7.50±25 kN. At the peak load condition test specimen was broken and the test results were calculated in the system which is connected to the UTM machine. The test results were tabulated below.

*Table 2. Tensile test results of E-Glass fiber reinforced epoxy.*

| Specimen Type GSM | Area of sample $mm^2$ | Maximum Force in KN | Displacement in mm | Tensile Strength in MPa |
|---|---|---|---|---|
| 225 | 106.666 | 7.560 | 10.25 | 70.875 |
| 300 | 114.244 | 7.230 | 10.66 | 63.286 |
| 450 | 123.084 | 4.590 | 8.32 | 87.292 |

*Table 3. Tensile test results of 1.0 wt% of MWCNTs, Alumina polymer.*

| Specimen Type GSM | Area of sample $mm^2$ | Maximum Force in KN | Displacement in mm | Tensile Strength in MPa |
|---|---|---|---|---|
| 225 | 97.376 | 7.68 | 11.89 | 73.654 |
| 300 | 105.386 | 8.45 | 12.05 | 69.345 |
| 450 | 113.486 | 6.85 | 16.46 | 97.235 |

*Table 4. Tensile test results of 1.5 wt% of MWCNTs, Alumina polymer.*

| Specimen Type GSM | Area of sample $mm^2$ | Maximum Force in KN | Displacement in mm | Tensile Strength in MPa |
|---|---|---|---|---|
| 225 | 95.720 | 7.770 | 11.72 | 81.175 |
| 300 | 98.386 | 9.120 | 11.30 | 92.697 |
| 450 | 113.486 | 13.500 | 15.86 | 118.957 |

*Table 5. Tensile test results of 2.0 wt% of MWCNTs, Alumina polymer.*

| Specimen Type GSM | Area of sample $mm^2$ | Maximum Force in KN | Displacement in mm | Tensile Strength in MPa |
|---|---|---|---|---|
| 225 | 99.673 | 7.45 | 12.09 | 79.364 |
| 300 | 107.567 | 8.35 | 13.76 | 90.389 |
| 450 | 112.486 | 7.23 | 17.12 | 100.342 |

The tensile test results for 450 GSM fiber reinforced epoxy Nanocomposites shows increased stress for E-Glass/Epoxy composite and decreased strain than other specimens. The ratio 1.5wt% of MWCNTs and ALUMINA Nanocomposites shows improved stress and tensile strength and decreased strain than E-Glass/Epoxy composite samples. The 450 GSM reinforced E-Glass fiber Nanocomposites shows 36.27 % improved results. 1.5wt% of MWCNTs is better than other specimens.

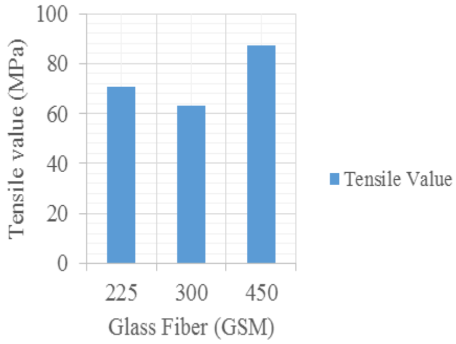


*Fig. 16.Tensile analysis of E-Glass/Epoxy polymer.*

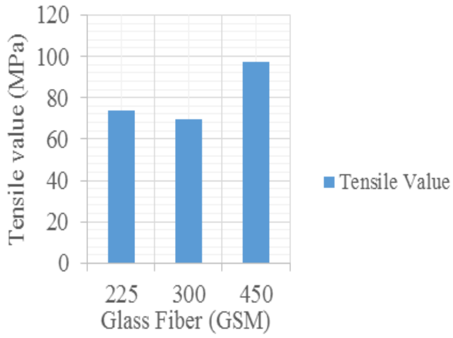


*Fig. 17.Tensile analysis of 1.0wt% MWCNTs.*

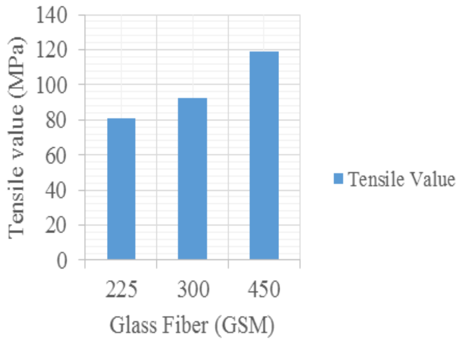


*Fig. 18.Tensile analysis of 1.5wt% MWCNTs.*

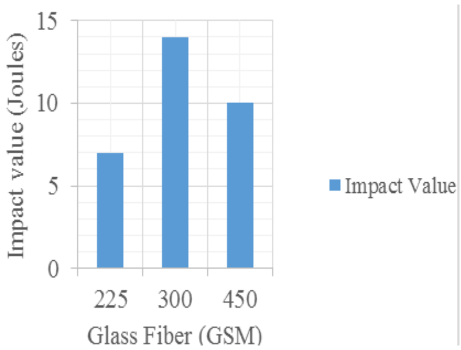


*Fig. 19.Tensile analysis of 2.0wt% MWCNTs.*

In this analysis Fig. 16 Tensile analysis of E-Glass/Epoxy polymer GSM 450 has good tensile strength value compared to 225 and 300 GSM. Fig. 17 represents 1.0 wt % of MWCNTs 450 GSM nanocomposite has high tensile value compared to E-Glass/Epoxy polymer. Finally Fig. 18 1.5 wt % of MWCNTs has over all good tensile strength, 36.27 % of increased tensile value compared to E-Glass/Epoxy nanocomposites. 225 and 300 GSM reinforced glass fibre epoxy with MWCNTs composites also has improved tensile value. But, overall 450 GSM composites has better tensile and impact value compared to other GSM.

**Impact Test:** Charpy Impact testing machine used for this experiment contains a heavy swing pendulum. This pendulum has the maximum capability of impacting energy is 343.977 J. A scale is provided in the machine, which range from 0 – 264 foot pound an indenter will move on this scale when pendulum is allowed from its horizontal static position to impact the V-notched specimen. There is a stand at the bottom of the machine where V-notched specimen is supported as a beam in horizontal position.

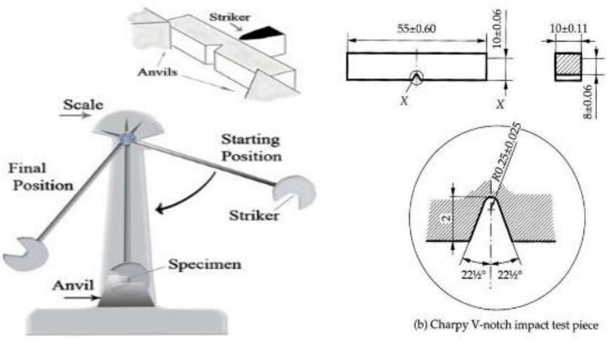


*Fig. 20. Apparatus for impact testing of material*

The impact test is done by placing a square shaped V notched specimen in the machine. Generally, the Charpy specimen has a square cross section of dimensions 10mm*10mm and contains a length of 50 mm, V notch of 2 mm deep with root radius of 0.25 mm. A heavy pendulum released from a known height strikes the sample on its downward swing and fractures it. After the test bar is broken, the pendulum rebounds to a height that decreases as the energy absorbed in fracture increases. By knowing the mass of the pendulum and the difference between its initial and final heights, the energy absorbed by the fracture can be measured. The measured test results were tabulated below

*Table 6. Impact test results of E-Glass fiber reinforced epoxy.*

| Specimen type GSM | Gauge length in mm | Width in mm | Thickness in mm | Area in $mm^2$ | Impact value in Joules |
|---|---|---|---|---|---|
| 225 | 50 | 12.08 | 8.83 | 106.666 | 07 |
| 300 | 50 | 13.52 | 8.45 | 114.244 | 10 |
| 450 | 50 | 13.15 | 9.36 | 123.084 | 14 |

*Table 7. Impact test results of 1.0 wt. % of MWCNTs, Alumina polymer.*

| Specimen type GSM | Gauge length in mm | Width in mm | Thickness in mm | Area in $mm^2$ | Impact value in Joules |
|---|---|---|---|---|---|
| 225 | 50 | 12.23 | 9.13 | 108.654 | 9 |
| 300 | 50 | 12.79 | 8.67 | 105.764 | 15 |
| 450 | 50 | 13.03 | 9.06 | 121.653 | 16 |

*Table 8. Impact test results of 1.5 wt% of MWCNTs, Alumina polymer.*

| Specimen type GSM | Gauge length in mm | Width in mm | Thickness in mm | Area in mm$^2$ | Impact value in Joules |
|---|---|---|---|---|---|
| 225 | 50 | 12.05 | 8.67 | 112.836 | 12 |
| 300 | 50 | 13.06 | 8.46 | 116.534 | 16 |
| 450 | 50 | 13.23 | 8.98 | 120.235 | 18 |

*Table 9. Impact test results of 2.0 wt. % of MWCNTs, Alumina polymer.*

| Specimen type GSM | Gauge length in mm | Width in mm | Thickness in mm | Area in mm$^2$ | Impact value in Joules |
|---|---|---|---|---|---|
| 225 | 50 | 11.95 | 8.01 | 95.720 | 10 |
| 300 | 50 | 11.94 | 8.24 | 98.386 | 14 |
| 450 | 50 | 13.32 | 8.52 | 113.486 | 15 |

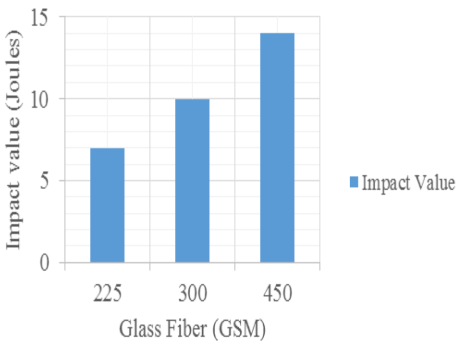


*Fig. 21.Impact analysis of E-Glass/Epoxy polymer.*

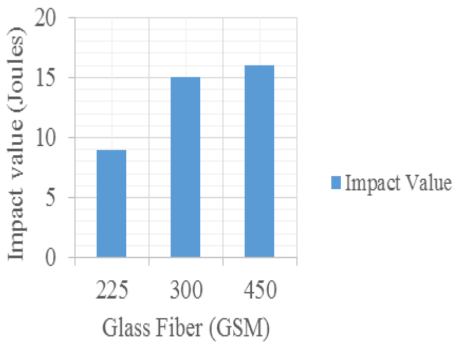


*Fig. 22.Impact analysis of 1.0wt%.*

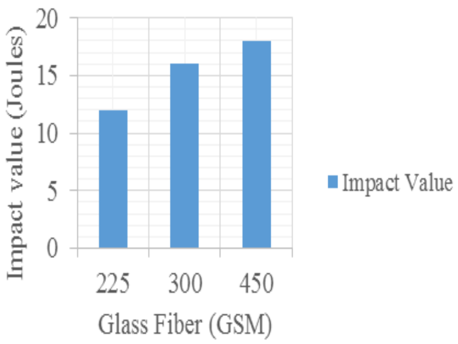


*Fig. 23.Impact analysis of 1.5wt% MWCNTs.*

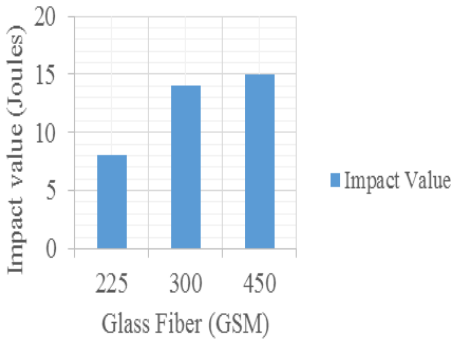


*Fig. 24.Impact analysis of 2.0wt% MWCNTs.*

In this analysis Fig. 21 Impact analysis of E-Glass/Epoxy polymer GSM 450 has good Impact strength value compared to 225 and 300 GSM. Fig. 22 represents 1.0 wt % of MWCNTs 450 GSM nanocomposite has high Impact value compared to E-Glass/Epoxy polymer. Finally Fig. 23 1.5 wt % of MWCNTs has over all good Impact strength 28.57 % of increased than the E-Glass/Epoxy nanocomposites.

## 7. Results and discussion

The tests were conducted for investigate the mechanical properties of MWCNTs. The test results show MWCNTs filled Nano composite has increased mechanical property than the E-Glass/Epoxy sample. The variation of result is due to the presence of impurities and debris.

The tensile test results of 1.5wt. % of MWCNTs with 450 GSM samples indicate better tensile strength of 36.27 % than the other weight rated 225 GSM and 300 GSM Nanocomposites. Finally 450 GSM of Nanocomposites has overall impact on its tensile value. The tensile performance was good for 1.5wt. % MWCNTs of 450 GSM samples than others.

In impact tests also the same 450 GSM reinforced epoxy/MWCNTs show more impact value than the other weight rated GSM Nanocomposites. The maximum impact value of 18 Joules has 450 GSM reinforced epoxy/MWCNTs Nanocomposites. The 450 GSM reinforced epoxy/MWCNTs Nanocomposites show 28.57 % improved impact results and 1.5wt% of MWCNTs is better than other specimens.

All these test results indicate 450 GSM E-Glass fiber reinforced 1.5wt. % of multi walled carbon Nanotubes has a huge boost on its mechanical behaviour. The 450 GSM E-Glass fiber reinforced Nanocomposites have good mechanical properties than the other samples.

## 8. Conclusions

In this experimental work the mechanical properties like tensile and impact strength of E-Glass/Epoxy and three different weight rated of MWCNTs with different GSM of E-glass fiber were examined. As per the outcomes the accompanying conclusions were drawn.

Mechanical behaviour is enormously enhanced in 1.5 wt. % of MWCNTs Nanocomposites with the impact of reinforced glass fibres at different GSM.

225 and 300 GSM reinforced MWCNTs Nanocomposites displayed significant change in tensile and impact property. Be that as it may, 450 GSM reinforced 1.5wt. % MWCNTs indicated better tensile and impact value.

450 GSM reinforced Nanocomposites have better tensile and impact performance than the other GSM Nanocomposites and it has high displacement value.

Finally 1.5 wt. % of MWCNTs is best weight rated compared to 1.0 wt. % and 2.0 wt. %. 450 GSM glass fiber reinforcement is better than 225 and 300 GSM.

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