Investigation of mechanical, thermal and water absorption behaviour of MWCNT's with AL_2O_3 reinforced polymer composite

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In this work, composite materials were developed using compression moulding method, which the composition of M2A1C (Epoxy + 2 wt % MWCNT +1 wt % Al_2O_3), M2A1.5C (Epoxy + 2 wt % MWCNT +1.5 wt % Al_2O_3) and M2A1C (Epoxy + 2 wt % MWCNT +2 wt % Al_2O_3). From the composition, M2A1.5C had improved the mechanical properties of 30%, 24% and 28% in tensile strength, flexural strength and impact strength, respectively, compared to the M2A1C. From the thermo-gravimetric examination, the critical change was happened during increasing of Al_2O_3, however, the M2A1.5C had a significant improvement within the residual mass and maximum temperature decomposition with compared to other composites. Hydrophobicity decreased in the M2A1C composition, due to the low density of the material in the composite. The study is exploring ways to improve the polymer-metal matrix hybrid composite materials to make them lighter and more affordable, as well as easier to use in light load applications.

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1. Introduction

Carbon nanotubes (CNT's) have attracted a great deal of attention since their discovery in 1991 because to their excellent features such as superior electrical and thermal conductivity, extremely high elastic modulus, tensile strength, and perfect flexibility [1,2]. Alumina oxide (Al_2O_3) has a very high hardness and wear resistance. However, its brittleness and post densification processing challenges limit its extensive applicability [3]. Researchers have explored new ways to add particulate materials such as silicon carbide, copper and aluminum oxide. They are widely used as reinforcements in aluminium matrix composites. However, the addition of metals limits industrial applications due to oxidation at maximum temperature [4,5]. The addition of aluminium oxide causes the compressive strength to decrease before increasing slightly as the sintering temperature increases, suggesting that reinforcement forces and dense structure are working together [6,7]. Studied Al_2O_3/Sic/Al hybrid composites to evaluate mechanical properties. They found that the tensile strength of the composites increased gradually with increasing the reinforcement volume fraction [8]. The wear resistance decreased slightly, with an increased Al_2O_3 sf proportion, but the friction coefficient stayed constant. There is no systematic try has yet been made to study the effects of the hybridization of CNTs and Al_2O_3 on the mechanical properties of pure aluminium-based composites, particularly by powder metallurgy method [9]. It's interesting to note that using other nanofillers including graphene oxide (GO), carbon nanotubes (CNT), and silicon carbide with MMC's in polymer matrix has also led to a number of unique outcomes. More critically, nanofillers outperform micro reinforcements in terms of mechanical characteristics. Nano-fillers have been used in several attempts to create composite materials with enhanced

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characteristics [10] According to this study, increasing 2% composition of MWCNT's to epoxy increased the epoxy composite's stiffness and ultimate strength by 14% and 17%, respectively. On the other hand, stiffness increased by 50% when SiC at 1 weight percent was added (11). Other studies have seen a mean increase in mechanical characteristics of 20 - 30% as well as improved fatigue performance with only 1.5 wt% nano-silicon carbide (SiC) [12]. Due to excellent material properties, MWCNT have proven their effectiveness in a wide range of applications in various technological fields such as aerospace, defence, automotive, naval applications and electronic components. The study of the composites in the CNT's - based polymer matrix nano - structured composite properties is not at all acceptable in medium load application [13]. From the literature study, only a limited fraction of research has been done in the MWCNT and Al_2O_3 based nano-structured composite. In this aspect, based on the compression moulding method, the Al_2O_3-MWCNT nanocomposites were developed. The Nano-composites mechanical characteristics, thermal properties, water absorption properties, surface behaviour studies, and interface research are described.

2. Experimental procedure

2.1. Materials

The MWCNT's were produced in-house by a chemical vapour deposition method and they were well-aligned and Al_2O_3 was obtained from Covai Seenu & Company, Coimbatore. MWCNT's and Al_2O_3 properties were given in Table 1.

Table 1. Properties of MWNT's and Al_2O_3 [4].

S. No	MWNT's	Unit	Al_2O_3	Unit
1	External diameter	10–30 nm	Size range	13 nm -20 nm
2	Length	0.5–500 µm	Chemical Composition	Aluminium- 52.92% and Oxygen- 47.04%
3	Ash	0.2%	Density	3600 kg/m^3
4	Purity	95	Molar weight	101.96 g/mol
5	surface area	40–300 m^2 /g	melting point	2040^o C
6	Amorphous carbon	3%	Boiling point	2977^o C
7	Electric conductivity	10^2–10^{-4} s/cm	Thermal conductivity	17.65 w/mk

2.2. Fabrication of composite

In this present research, sample is prepared by the constant mixture of MWCNT's at 2.0% and adding the Al_2O_3 hybrid powder at 1.0%, 1.5%, and 2.0% by wt%, respectively, into the epoxy resin. Initially, the mixture was mixed uniformly epoxy with Al_2O_3 and MWCNT's using mechanical stirring as per the mentioned weight ratio. After that, the mixture was poured in bottom of the die. Followed by, top die is closed in bottom of the die using compressing machine [13]. After 24-hour, die was separated and composite plate are removed from the die and shown in fig. 1. Then composite plate was cut by as per ASTM standard for finding the properties of the composite materials. In this research work, fabricating the samples from Herenba Instruments & Engineers, Chennai, Araldite LY 556 (epoxy resin), Aradur 917 (hardener), and MWCNTs from Modern Scientific Co, Coimbatore and designation of composite is presented in the Table 2.

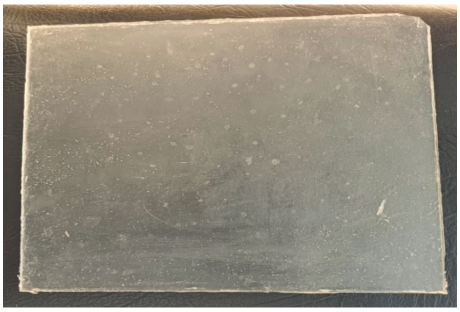

Fig. 1. MWCNT and Al_2O_3 Reinforced Epoxy Hybrid Composites Plate.

Table 2. Designation of Composites.

Composite	Composition
M2A1C	Epoxy + 2 wt % MWCNT +1 wt % Al_2O_3
M2A1.5C	Epoxy + 2 wt % MWCNT +1.5 wt % Al_2O_3
M2A2C	Epoxy + 2 wt % MWCNT +2 wt % Al_2O_3

2.3. Static Mechanical Properties

An Instron tensile tester was used to determine the tensile strength and modulus of MWCNT and Al_2O_3 Polymer composites. Tests were performed on specimens made up of dog bone, cut with a micro-grinder, at a crosshead speed of 3 mm/min in accordance with ASTM D 638 [21]. Machine bend test with 5mm/min cutter head speed and following ASTM D790, composites are rated for their ability to bend in three directions. The impact resistance of composites was evaluated using an electronic impact tester according to ASTM D 256 [22]. The laminates were cut into test pieces measuring 64 × 13 × 3.2 mm^3 and a groove notched [14]. The MWCNT and Al_2O_3 reinforced epoxy composite Tensile and Flexural samples are shown in Fig. 2.

Fig. 2. Tensile , Flexural and Impact Specimens of MWCNT 's and Al2O3 Reinforced Epoxy Hybrid Composites

3.4. Water Absorption Test

The ASTM D 5229 standard [15] is used to test the moisture sensitivity. To investigate the impact of fibre treatments on the water absorption of composites, specimens were submerged in a sealed bath of distilled water (100% humidity) at room temperature. Before being submerged in water, all of the samples spent 24 hours in an oven set at 60°C. The moist surface of the sample was swiftly dried and weighted after it was removed from the water at predetermined intervals. The following equation [10] was used to determine the moisture content.

$$W\% = \frac{(W_t - W_0)}{W_0} \times 100\% \quad (1)$$

where, Wt is the weight of the wet composite specimen at time t and W_0 is the mass of the oven dry specimen.

3.5. X-ray diffraction (XRD)

The crystallinity index was calculated using X-ray diffraction analysis on powdered materials, utilising an XRD analyser of P analytical manufacture and X pertpro model machine employing Cu k radiation with continuous scan [16].

3.6. Thermal Properties

Using a machine of the Hitachi STA7300 type, thermogravimetric analysis (TGA) and derivative thermogravimetry (DTA) were performed at temperatures ranging from 28 to 500 °C and a heating rate of around 20 °C/min using an alumina pan [2].

3.7. Scanning Electron Microscope (SEM)

After the tensile specimen fracture, the tensile strength specimen's mechanism of failure was examined using the ICON and Quanta 200 Mark II machines with accelerating voltages ranging from 0.2 to 30 kV [9].

4. Result and discussion

4.1. Analysis of Mechanical Properties

Table 3 shows the variation of the tensile and flexural strength with increase in the Al_2O_3 content in the hybrid composites. Considerable improvement in the tensile and flexural strength with increase of the Al_2O_3 in the reinforcement. Compared to the M2A1C composition, the tensile and flexural strength was 15% and 12% and increase in the M2A1.5C composition. Followed by, Youngs modulus value are produced the maximum value of 1.6 GPa for the M2A1.5C composition.

Table 3. Mechanical Properties of MWCNT 's and Al_2O_3 Reinforced Epoxy Hybrid Composites.

Materials	Tensile Strength (MPa)	Flexural Strength (MPa)	Hardness (HV) (GPa)	Young's Modulus (GPa)	Fracture Toughness (KIC) (MPa $M^{1/2}$)
M2A1C	64.58	347	16	1.2	4.5
M2A1.5C	75.42	395	19	1.6	7.8
M2A2C	70.56	290	18	1.4	6.7

Table 3 shows the variation the hardness and Fracture toughness with increasing of Al_2O_3 in the composite. While increasing of Al_2O_3 content, initially the hardness value is considerably increased first and decreased, reaching its highest point at 1.5 wt%. The maximum composite modulus prevents localised plastic deformation, which raises the hardness. The increased strength in nanocomposites with increased MWCNT and Al_2O_3 content can be attributed to the reinforcement of the polymer matrix, which is supported by an improvement in ductility. This makes it easier for the matrix to effectively transmit stress to the both reinforcements [22].

4.2. X-ray diffraction (XRD) Analysis

Fig. 3 dedicates the X-Ray Diffraction Analysis (XRD) pattern of the Al_2O_3 and MWCNT for hybrid nano composite. Al_2O_3 was obtained the with two major peaks at 22.4° and 24.2°. The increase in crystallinity has been linked to a larger peak intensity in the hybrid nanocomposite.

This might occur as a result of the contact and crystallisation behaviour of MWCNT with Al_2O_3 during the blending process [21]. MWCNT also shows two main peaks at about 2θ= 28° and another broad peak centred at around 2θ= 37°, corresponding to the (002) reflection planes with interlayer distances of 3.113 and 2.215, respectively.

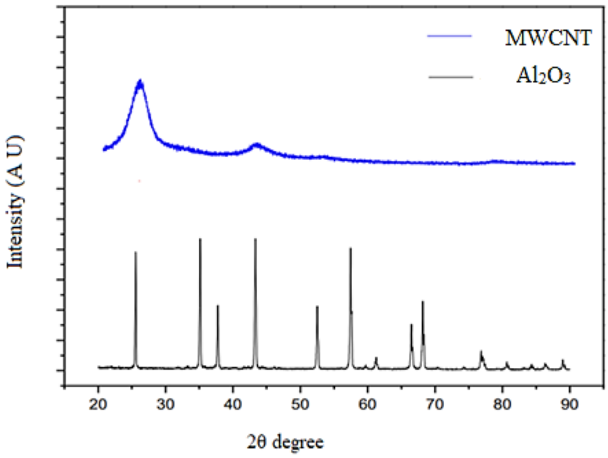

Fig. 3. X-Ray Diffraction Analysis of MWCNT 's and Al2O3 Reinforced Epoxy Hybrid Composites

4.3. Water Absorption Properties

Fig. 4 shows the water uptake for MWCNTs with Al_2O_3 reinforced epoxy hybrid composites as a. function of time. After 30 to 180 minutes of immersion, a test was conducted to determine saturation. The linear rise in moisture absorption in the curves, regardless of the immersion period, illustrates the behaviour during the first exposure time. The equilibrium moisture content demonstrates that M2A1C had a greater water absorption rate than M2A2C. The presence of hydrophilic groups (OH and COOH) on the MWCNT may be the cause of the M2A1C hybrid composite's higher water absorption [20].since the addition of MWCNTs increased the crystallinity of Al_2O_3 and facilitated its crystallisation to allow water to infuse the matrix. The increased Al_2O_3 concentration may absorb less moisture and so enhance bonding to the polymer matrix, resulting in enhanced performance in a humid environment [13].

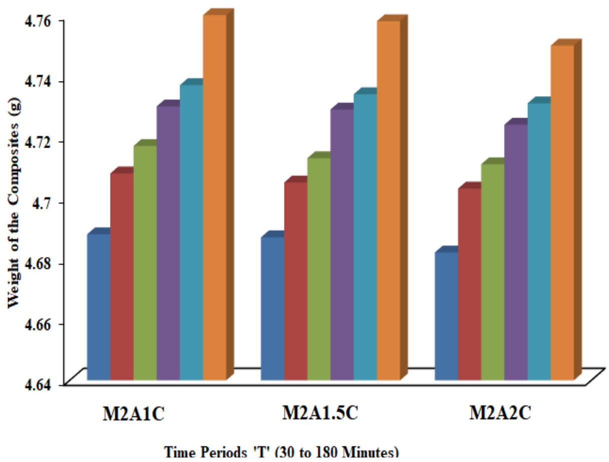

Fig. 4. Water absorbtion weight of MWCNT 's and Al2O3 Reinforced Epoxy Hybrid Composites.

4.4. Thermogravimetric Analysis

Figures 5 and 6 show thermogravimetric analysis (TGA) and derivative thermogravimetry (DTA) of a hybrid composite. Only the significant thermal degradation losses from the various composites are conserved among the three compositions. The earliest stage of heat degradation occurred between 60°C and 340°C, with a weight loss percentage of 22.1% [20]. The thermal deterioration of the second stage begins at 373°C and gradually decreases, with a mass loss of 62.1%. The third phase of deterioration concludes at 480°C as well, with a mass loss of 91.6% [19].

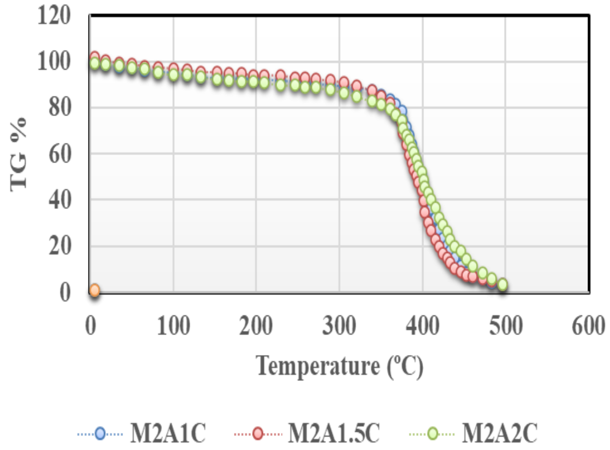

Fig. 5. Thermo-Gravimetric Analysis of MWCNT 's and Al2O3 Reinforced Epoxy Hybrid Composites.

For M2A1C , the lowest mass loss rate value is found. This takes advantage of the fact that melting point temperature increases and mass loss melting speed rates drop when MWCNT weight ratio increases, as illustrated in Fig. 5. The composite material of M2A2C, with a residual yield of 6.4%, and the derivative thermogravimetric value is 1156.40 g/min with a maximum DTG temperature of 452.32 °C [19].

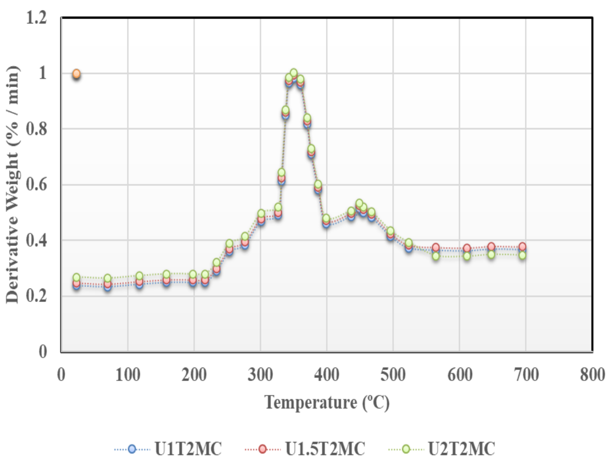

Fig. 6. Derivative Thermogravimetry of MWCNT 's and Al2O3 Reinforced Epoxy Hybrid Composites

4.5. Analysis of Scanning Electron Microscope (SEM)

Fig. 7 displays the image of scanning electron microscopes used to investigate the nanocomposite structure and matrix distribution. It is clear from the SEM picture 7 (a) that Al_2O_3 particles have rough surfaces and are balanced. Meanwhile, the porous morphology of Al_2O_3

particles is observed, which leads reduce the mechanical properties of the hybrid composite [18]. The MWCNT structure and the material's nano-scaled design are confirmed by Figure 7 (b). it shows the consistent mixing of Al_2O_3 particles with MWCNTs across a polymer matrix. The relatively uniform distribution Across the whole matrix of the MWCNT's and Al_2O_3 can also be seen suggesting a successful suspension [13]. Figure 7 (c) shows a SEM picture of an M2A2C powder combination with huge agglomerates of MWCNTs entangled and clustered with Al_2O_3 particles [17]. Higher MWCNT and Al_2O_3 concentrations cause agglomeration, resulting in nonuniform densification of the composites and loss of their mechanical characteristics.

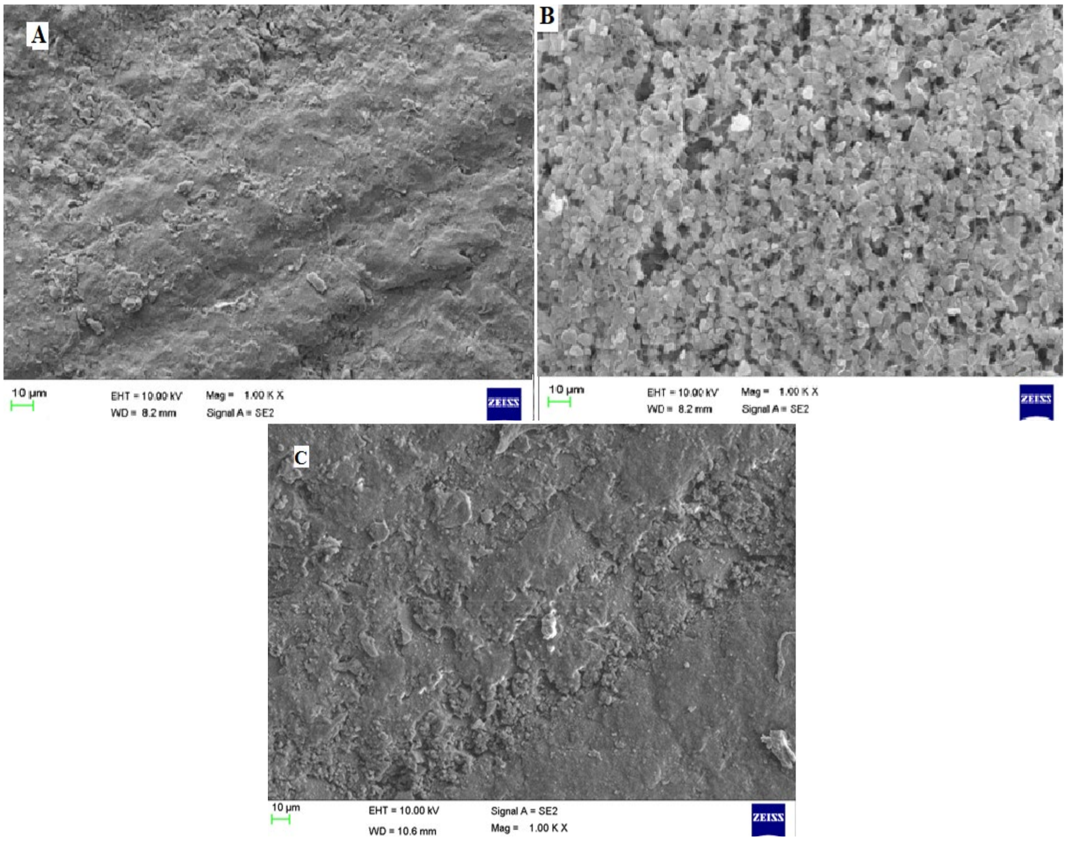

Fig. 7. Scanning Electron Microscope of a) M2A1C b) M2A1.5C c) M2A2C.

5. Conclusions

The characteristics of mechanical , moisture and thermal behaviour of MWCNT and Al_2O_3 reinforcement with epoxy based hybrid composites was investigated. The following results show that:

The X-ray diffraction peaks of the matrix changed to greater angles when MWCNT's and Al2O3 were added, indicating that the matrix still contains compressive stress. As 1.5 wt% Al_2O_3 s were added, the tensile and flexural strength of the hybrid composite reached a maximum value of 75.42 Mpa and 395 Mpa , 15% and12% higher than that of M2A1C.While increasing of Al_2O_3 content, initially the hardness and toughness value is considerably increased first and decreased, reaching its highest point at 1.5 wt%.In spite of The water absorption resistivity of composites increased significantly as the Al_2O_3 concentration increased, whereas the water absorption magnitude increased when the MWCNTs content was 2.0 wt%.

The composite's of TGA analysis shows that when the weight ratio of Al_2O_3 increases and melting point temperature increased, meanwhile mass loss melting speed rate reduced.MWCNT's with Al_2O_3 Reinforced Polymer Composite shows significant potential as a complementary reinforcement for the creation of low-cost, high-performance aluminium hybrid composites.Based on the above results , this material suggested to develop the replace the nylon or plastic spur gear for light loading applications.

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