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Moisture Absorption Effects on the Mechanical Properties of Epoxy Nano Composites

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ABSTRACT

Plastic composite material has been in to frontier of research as one of the new competitive materials in engineering. Especially, fiber reinforced plastic (FRPs) is a relatively new class of composite material manufactured from fibers and resins, and has proven efficient and economical for the development and repair of new and deteriorating structures. In this work, we report the effect of moisture on the mechanical properties of epoxy composites strengthened with MWNTs. Different composition of carbon nanotubes (MWNT) (0.1 -0.2%) were mixed with epoxy matrix by sonication method and castings were prepared by moulding technique. The different mechanical properties were evaluated at room temperature. One set of samples were immersed in distilled water at 50°C for moisture absorption and strength degradation studies. The moisture absorption data on each specimen is tabulated and analyzed for the absorption characteristics. From the moisture absorption curves, maximum moisture content and diffusion coefficients were calculated for all the samples. The wet mechanical properties important for the technological applications were generated including fracture toughness, flexural strength and modulus. Also, the specimens were tested for the degradation studies after the absorption of maximum moisture. In addition to the above investigations, the hardness of the resulting nano composites was also checked. All the studies were carried out to characterize neat resin castings of the resin system under study with and without carbon nano tubes and thus generate some data on various properties as mentioned above. However there is a lot of scope for future work on neat resin castings and as well as at laminate level on these nano composites to optimize these composites for practical aerospace applications especially for the fuselage of the air flights.

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Nomenclature

S= Tensile Strength
E= Modulus of Elasticity V= Volume Fraction
f= Fiber m= Matrix
c= Composite
E_f= Youngs modulus of fibre
V_f= Volume fraction of fibre
E_m= Youngs modulus of matrix V_m= Volume fraction of matrix W = Weight of moist specimen W_d =Weight of dry specimen
C=concentration of moisture in specimen.
C_i=concentration of moisture at any time 'i'.

Introduction

Following the technological developments industries are searching for lighter weight, higher strength and safer material to meet the demands of structural designs and for economic benefit. In order to extend the application area of plastics, plastic composites are developed by adding reinforcement materials to the polymer matrix. Some of the reinforcements used in structural and industrial applications are Carbon, Aramid and Glass fibers the most commonly used is glass fiber. Plastic composite material has therefore become one of the new competitive materials in engineering. Fiber reinforced plastic is a relatively new class of composite material manufactured from fibers and resins, and has proven efficient and economical for the development and repair of new and deteriorating structures. The mechanical properties of FRPs make them ideal for widespread applications in various industries worldwide. The enhancement of the mechanical and structural properties due to addition of fibers makes FRPs ideal materials for aircraft parts, aerospace structures, and railways, marine and other industrial applications [1]

C_B=concentration of moisture at the boundaries of the specimen.
D_C= diffusion coefficient. G=dimensionless absorption Parameter.
h=thickness of the composite specimen under Consideration.
M_t=moisture content at any time't'.
M_m=moisture content upon saturation.
t=time of exposure of the specimen to the test environment.
$\ln(D_c t/h^2)$=dimensionless diffusion parameter.

Experimental Details

The main aim of this chapter is to present an overall picture as to how the studies related to this project were conducted. This chapter includes detailed descriptions on Neat Resin Castings with and without nano fillers (CNT), the experimental setup used, the procedures adopted during the conduct of studies related to this project, the moisture absorption studies and mechanical properties of both wet and dry castings.

Preparation of Neat Resin Casting: This is the first stage of the experimental process. The neat epoxy resin castings were prepared using materials such as Epoxy resin, Amine hardener and Diluent

Calculations for Resin Hardener System:
Density of epoxy Resin: 1.2 g/cc Matrix ratio (Resin + Hardner): 100:12
Volume of the mould (cc): 25cmX25cmX0.3 cm
Weight = Density x volume
Total Weight (resin + hardener) required = density of resin X volume of the mould
=1.2 X 250 X 250 X 3 = 225grams
Mix ratio for the epoxy system (LY556 + HY951) is 100:12
i.e., Resin required = (100/112) x 225 = 200gms
Similarly Hardener required = (12/112) x 225
= 24.10gms

Procedure for preparing Neat Resin Casting:
[1]Two beakers were taken and washed with acetone and keep it for some time so that it dries. As per the ratio of resin and hardner that is 100:12 the weight of resin and hardener was calculated. [2]Weigh the resin in one beaker and hardener in other beaker Mix the resin with 10ml of diluent K77 (which reduces the viscosity of resin) thoroughly .[3]Place the two beakers in the vacuum oven for degassing so that the moisture in the resin and hardener vanishes to get a clear Neat resin casting with no air bubbles [4]Both the beakers should be in the vacuum oven till it is completely degassed and a continues monitoring is required so that the resin does not come out of the beakers. [5]Now clean the two mould plates with acetone apply Frekote FMS (Mould Sealer) on to the surface of the mould with brush so that the finished surface having small pores gets vanished. [6]After sometime apply Frekote 770-NC (Mould releasing agent) so that the casting should get released easily from the mould different types of releasing agents has been used out of which Frekote 770-NC was more advantageous compared to PVA (Poly Vinyl Alcohol) in releasing the casting easily from the mould [7]Insert spacer (Based on the thickness of casting) of the required dimensions between the two mould plates and seal the sides of the mould with silicon sealant. Clamp the sides of the mould with C- clamps. Now remove the two beakers from the vacuum oven mix the hardner with the resin and stir it in a stirrer for 5mins and pour into the mould. Now allow the mould for 24hours at room temperature and then for post curing in temperature oven at 50°C/1/2hr, 70°/1hr and 85°/2hrs.

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Equipments Used for the preparation of Neat Resin Castings

1. Vacuum oven used for degassing the epoxy resin System

Fig 1: Vacuum Oven

2. Ultra Sonicator used for evenly dispersing nanoparticles in liquids

Fig 2: Ultra Sonicator

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3.Post curing was done to verify that the castings are completely cured

Fig 3: Post curing oven Casting Produced

Fig 4: Neat Resin casting Preparation of Casting with Multi Walled Carbon Nano Tubes

(MWCNT):
Matrix System: Epoxy Resin (LY556) & Amine Hardener (HY951)
Diluent: K77
Carbon Nano Tubes: MWCNT (Purity > 98
%, Length=1-5 microns & Diameter= 6 – 20 nm)
Solvent: Ethanol

Fig 5: Castings with MWCNT

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Cutting of specimens using water jet cutting machine:

After the castings are prepared, cutting of the specimens was done as per the standard dimensions

Fig 6: Water jet Cutting Machine

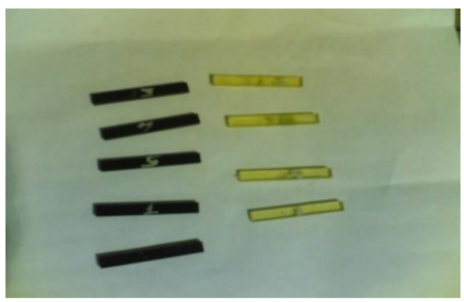

Fig 7: Sample Specimens for Testing of Mechanical Properties:

Fig 8: Universal Testing Machine

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The mechanical properties (Fracture toughness, Flexural strength and modulus) of the dry specimens (with and without CNT) were determined using universal testing machine (INSTRON)

Moisture Absorption Studies:

To study the moisture absorption behavior, specimens were placed in a constant temperature distilled water bath maintained at 50°C after taking its initial dry weights**.** The specimens were periodically taken out from the water bath to measure their weight gain as outlined below The specimens were first taken out of the bath and were placed on a filter paper. Each specimen was wiped with the filter paper to remove the free moisture adhering to its surfaces as well as the edges. Then the wiped specimens were weighed on an electronic balance and immediately returned to the water bath. This was done in order to minimize any possible loss of moisture from the specimen at room temperature conditions. The percentage moisture gain by the specimen was calculated by the equation as follows

$$M = \frac{(W - W_d)}{W_d} \times 100$$

Diffusion and degradation Studies:

The diffusion coefficient D_c for each specimen was calculated using the equation given as

Fig 9: Specimens in constant water temperature bath

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Results and Discussions

This section deals with the tabulation of the results obtained from the experimental studies, and has been further divided into sub sections devoted to results from experimental studies related to mechanical properties, moisture absorption and strength degradation studies.

The dry mechanical properties (flexural strength and modulus, fracture toughness) of neat resin casting (NRC) and nano composites are shown in the tables below

$$D_c = \Pi\left(\frac{h}{4M_m}\right)^2\left(\frac{M_2 - M_1}{\sqrt{t_1} - \sqrt{t_2}}\right)^2$$

Where

$$\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}} = \text{Slope}$$

Mechanical strength degradation studies were carried out after the specimens absorbed maximum moisture content percentage degradation was calculated using the equation given as

$$\%\ \text{degradation} = \frac{\text{Dry Strength} - \text{Wet Strength}}{\text{Dry Strength}}$$

From the table **1** below it is observed that both flexural strength and modulus of nano composite (0.2%MWCNT) were increased significantly as compared to neat resin casting and casting with 0.1%MWCNT. This is due to poor interfacial bonding b/w the nanotubes and epoxy matrix in case of 0.1%.

Material	Flexural Strength (kg/mm^2)	Flexural Strength (N)	Flexural modulus (kg/mm^2)	Flexural Modulus (N)
Neat Resin Casting	12.12	118.89	420.12	$4.12x10^3$
NRC with 0.1% MWCNT	11.45	112.32	354.17	$3.47x10^3$
NRC with 0.2% MWCNT	13.80	135.37	432.8	$4.24x10^3$

Table 1: Flexural strength and modulus of NRC and nanocomposites

From the table **2**, it is observed that fracture toughness of nano composite is less than that of neat resin casting. This is due to poor dispersion of nanotubes in the epoxy matrix.

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Material	Fracture Toughness (Mpa m½)
Neat Resin Casting	4.505
NRC with 0.1% MWCNT	3.649
NRC with 0.2% MWCNT	3.103

Table 2: Fracture toughness of NRC and nanocomposites

From the table **3** it is observed that by increasing the percentage of MWCNT the moisture absorption is decreased.

Material and Percentage Moisture gain fot	Time (hrs)	Sqrt time (hrs)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
NRC	1896	43.54	2.53	2.596	2.647	2.583	2.666	2.604
0.1% MWCNT	1896	43.54	2.384	2.371	2.388	2.451	2.424	2.404
0.2% MWCNT	1536	39.19	2.171	2.165	2.160	2.158	2.155	2.161

Table 3: Percentage Moisture gain for NRC and casting with 0.1% MWCNT 0.2% MWCNT

Calculation of Diffusion parameters

Sl.No	Material	%Mm	Dc × 10^{-7}(mm^2/sec)	Time of exposure (Days)
1.	Neat Resin Casting	2.60	4.793 × 10^{-7}	64
2.	NRC with 0.1% MWCNT	2.40	5.408 × 10^{-7}	64
3.	NRC with 0.2% MWCNT	2.16	7.968 × 10^{-7}	64

Table 4: Diffusion Parameters of NRC and Nano Composites

Degradation studies

The absorption of moisture will reduce the strength of the composite. The wet mechanical properties of neat resin casting with 0.2% carbon nano tubes are represented.

	Flexural Strength (kg/mm²)			Flexural Modulus (kg/mm²)		
	Dry	Wet	% Degradation	Dry	Wet	% Degradation
Average	13.61	10.30	24.45	444.4	432.8	5.818

Table 5: Degradation of Flexural strength and modulus of nanocomposites

Sl No	Fracture Toughness (Mpa m½)		% Degradation
	Dry	Wet	
Average	3.10	2.302	25.80

Table 6: Degradation of Fracture toughness of nanocomposites

From the above table, it is seen that the fracture toughness degradation is more compare to flexural strength degradation and is around 26%.

Conclusion

Epoxy matrix is modified with multi walled carbon nanotubes. Castings were prepared and properties were evaluated and tabulated. The time consumed was more to freeze the correct method for the preparation of the castings with and without nano fillers. From this, it can be concluded that some of the properties were significantly changed with the addition of nanotubes.

Mechanical properties like Flexural strength and modulus were increased with 0.2% nanotubes, as compared to lower CNT concentration. Fracture toughness values were not changed significantly with the nanotube inclusions due to poor dispersion of nanotubes in the epoxy matrix (FESEM images) and also nanotubes in the composite could not take up the full load longituidinal direction for the same reason. Moisture absorption (M_m) values are 2.6% for neat resin casting and 2.1% for nanocomposites. Moisture absorption (M_m) values decrease with increase in CNT concentration.

Diffusion Coefficient (Dc) values increase with increase in CNT concentration. Degradation of flexural strength and modulus are around 24% and 5.8%, fracture toughness degradation will be 26%. Properties were not changed significantly for addition of lower concentration of nanotubes, Addition of still higher concentration of nanotubes may give significant changes in the properties.

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