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INFLUENCE OF CARBON FIBERS (CF'S) AND MULTI WALLED CARBON NANOTUBES (MWCNT'S) ON THE MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF POLYMER BASED MATRIX FOR AVIATION APPLICATIONS

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Abstract- This research investigates the reinforcement effects obtained by inducing Carbon Fibers (CF's) and Multi Walled Carbon Nanotubes (MWCNT's) at micro and nano level in a polymer based matrix. Percentage composition of the fillers were varied in three different proportions that is 0.15, 0.5, 0.75% by weight of polymer matrix, these compositions were varied in order to check the best efficacy of reinforcement proportion for optimum results. Homogeneous and uniform distribution of nanoparticles in the holding matrix was achieved with the help of Ultrasonicator. The specimens casted as per ASTM standards were tested for mechanical properties like Load deflection criteria, tensile strength. The test results of reinforced specimens were compared with a controlled specimen, to determine the changes obtained because of the reinforcement phase. Spectroscopic analysis was performed using Field Emission Scanning Electron Microscopy (FESEM) to identify the nanofillers interaction with the holding matrix such as dispersion, tailoring of different layers of polymers etc. Energy-dispersive X-ray spectroscopy (EDS) was conducted as an elemental analysis to know the chemical composition of the specimens and their effects. Specimen containing CF's and MWCNTs with 0.15% composition showed optimum results in terms of Ultimate load carrying capacity and tensile strength as compared to a plain epoxy.

Keyword-Carbon fibers, Multi walled carbon nanotubes, Energy Dispersive X ray Spectroscopy, Mechanical properties, Field Emission Scanning Electron Microscopy.

I. INTRODUCTION

Polymer composites in the field of material science have evolved significantly. The enormous use of polymers and polymer based composite materials in the aviation industry is attributed to their extraordinary combination of properties [3]. Over the years research in field of polymers has revealed that a polymer matrix in different fractions of one or more reinforcing phases, can significantly improve the mechanical properties of polymers. Although CNTs are ideal reinforcement phase but their agglomeration phenomenon eventually results in degradation in the expected efficiencies of the polymer composites [1,4,6], this can be attributed to mainly two reasons: one being non-uniform dispersion of CNT's and the other being insufficient bonding between the polymer/filler interface [1]. Previous research findings show improvement in the mechanical performance of polymers induced with carbon fibers because of their unique aspect ratios [10].

As strength to weight ratio has been the governing factor over the years in case of aviation structural applications, fiber-reinforced composites are promising approach as alternatives for metals in various weight based applications and different commercial enterprises [7,8], all of which can be attributed to their extraordinary properties like stiffness to weight ratio, long fatigue life, corrosion resistance for increased humidity surroundings, wear resistance etc. [2] Plastics are good in handling tough and impact loads but weak in addressing ductile or tensile loads this weakness can be overcome by using reinforcement with high aspect ratio. CNTs are considered as a standout amongst the most encouraging reinforcement materials as they fall under the category of diamond like carbon materials which have high Brinells Hardness Number (BHN), using these as reinforcing phase not

only enhances the strength but also ductility to highest limits, this concept is further supported by the upcoming era of multifunctional composite materials, perhaps the most remarkable improvement shown in the tensile properties of a polymer through the dispersion of CNTs [3,5]. These molecular scale multi walled tubes of carbon have extraordinary mechanical properties like high tensile strength and tensile modulus, high flexibility, low density, large aspect ratio etc. [1,9] all of which makes it an ideal reinforcing agent. In this proposed work, reinforcement is carried out at very minute proportion taking weight of the polymer matrix as standard, carbon fibers and CNTs to address reinforcement both at micro and Nano level in the holding matrix is done to study the mechanical performance having unique advantages over monolithic materials.

II. EXPERIMENTAL PROGRAM

A. Materials

The fillers used in this experiment are Carbon Fibers and Multi Walled Carbon Nanotubes in epoxy based holding matrix, both the fillers are of Industrial grade procured from Sigma Aldrich Co USA. The properties of materials used for the study are mentioned in Table 1 and Table 2.

TABLE 1:PROPERTIES OF CARBON FIBERS.

Specifications	Dimensions
Density	1.8 (g/cm^3)
Length of fibre	10 (mm)
Diameter of fibre	8 (µm)
Weight of fibre	200 (g/mm^2)
Poisson's ratio	0.25
Tensile strength	3500 (N/mm^2)
Tensile modulus	285000 (N/mm^2)

B. Method

1) Dispersion Technique and Preparation of specimen:

Addition of Carbon fibers to epoxy results in asymmetric orientation of the fibers because of the mechanical joggling of carbon fibers in the holding matrix this is further aggravated by the increasing viscosity of the holding matrix. A prior disentanglement of the carbon fibers is required to reduce the asymmetric random distribution of the filling fibers in the holding matrix in order to achieve this carbon fibers are first disentangled as much as possible so as to separate as many threads as possible because these get easily entangled leading to non-uniform distribution of the fibers when mixed with epoxy.

Dispersion of CNTs against their agglomeration due to Vander Waals bonding is a key issue which needs to be given prime importance in the initial phase for development of nanocomposites [1,6]. The Pre-dispersion of MWCNTs is carried out by sonication in water. The method of sonication, duration of sonication and the method of casting specimens were maintained uniformly throughout the experiment. 10% of hardener is added by the weight of epoxy resin to act as a crystallising agent since epoxy is a thermosetting resin to initiate crystallization temperature. Different proportions of MWCNT's and CF's were added as reinforcement fillers to the polymer matrix as shown in Table 3. The whole mixture was sonicated for a period of 120 min to achieve uniform dispersion of fillers in the holding matrix [1].

TABLE 2: PROPERTIES OF MWCNTS.

Specifications	Dimensions
Density	1.8 (g/cm^3)
Length of fibre	5 (mm)
Diameter of fibre	10–30 (nm)
Fibre thickness	0.3 (mm)
Purity	95 (%)
Surface area	350 (m^2/g)

Tensile strength	3500 (N/mm^2)

C. Testing:

The mechanical performance of the polymer composite material reinforced with MWCNTs and CF's is validated by tensile test. Tensile test was carried out as per ASTM D638 standard. As a means of spectroscopic analysis Field Emission Scanning Electron Microscopy (FESEM) was utilized to study the effective dispersion phenomenon and microstructure bonding of MWCNTs in polymer matrix. Energy-dispersive X-ray spectroscopy (EDS) was used to investigate thermal analysis to determine the percentage of other elemental composition and their effects on the mechanical performance parameters.

TABLE 3: PROPERTIES OF MWCNTS.

S.I. No	Specimen reference	Specimen Constituents	Percentage of fillers (by weight of epoxy)
1	A	Plain Epoxy	Nil
2	B	Plain Epoxy + CF's	0.15
3	C	Plain Epoxy + CF's	0.50
4	D	Plain Epoxy + CF's	0.75
5	E	Plain Epoxy + CF's + MWCNT's	0.15
6	F	Plain Epoxy + CF's + MWCNT's	0.50
7	G	Plain Epoxy + CF's + MWCNT's	0.75

III. RESULTS AND DISCUSSION

Trials on different varying composition of fillers were carried out in order to arrive at the best possible combination of fillers to achieve highest strength among the casted specimens. In order to assess ideal percentages of MWCNTs and CF's required for reinforcing plain epoxy specimen, tensile test was used as the investigation factor [1].

From the Table 4, B and E specimens have shown increase in the ultimate load carrying capacity of the polymer as compared to plain epoxy specimen this can be due to the fillers which provide strength and in some case interlocks which bears extra load.

TABLE 4: ULTIMATE STRENGTH, ULTIMATE LOAD AND DEFLECTION READINGS OF SPECIMENS.

S. I. No.	Specimen Reference	Specimen Constituents	Ultimate tensile strength (N/mm^2)	Ultimate load in (KN)	Maximum deflection in (mm)	Percentage change in Ultimate load
1	A	Plain Epoxy	24.61	1.60	3.33	Nil
2	B	Plain Epoxy + 0.15% CF's	28.46	1.85	4.84	+15.64
3	C	Plain Epoxy + 0.50% CF's	29.23	1.90	1.74	+18.77
4	D	Plain Epoxy + 0.75% CF's	24.61	1.60	1.77	0
5	E	Plain Epoxy + 0.15% CF's + 0.15% MWCNT's	33.08	2.15	3.10	+34.38
6	F	Plain Epoxy + 0.50% CF's + 0.50% MWCNT's	24.61	1.60	2.70	0
7	G	Plain Epoxy + 0.75% CF's + 0.75% MWCNT's	13.08	0.85	0.70	-46.89

Also it can be concluded from table 4 that with the increase in filler content up to a certain composition there is increase in strength for the specimens C & F, further increase in composition of fillers leads to the decrease in the strength of the specimens as compared to a plain epoxy this could be due to the increase in the resistance due to deformation of the holding matrix resulting in hardness of the specimen leading to the brittle nature of the specimen, the effect of which can be observed in Figure 1. Also the increase in composition might have reduced the strength because of the agglomeration of the fillers leading to voids and porosity in the matrix which may act as weakness for the applied loads.

In the aviation industry power to weight ratio is a vital factor, there have been efforts over the years to lessen the weight of the structure in order to enhance power of the aviation equipment's. Polymer nanocomposites are not only promising in the reduction of the weight of aircrafts but also other parameters such as fuel efficiency, air-conditioning. CF's and MWCNT's can be proposed as an alternative in the fuselage of the aircraft and where structural stability is of chief importance, mostly as they hinder the growth of cracks at micro and nano level, thereby increasing tensile strength of structural components. Polymer nanocomposites can act as a substitute for the existing aluminum alloys in main frames of the aircraft, having wide scope in aerospace industry [11,4]. However recently Boeing, has developed an aircraft built entirely with carbon fibers eliminating aluminum sheets in the body (fuselage), reducing a lot of dead weight on the aircraft.

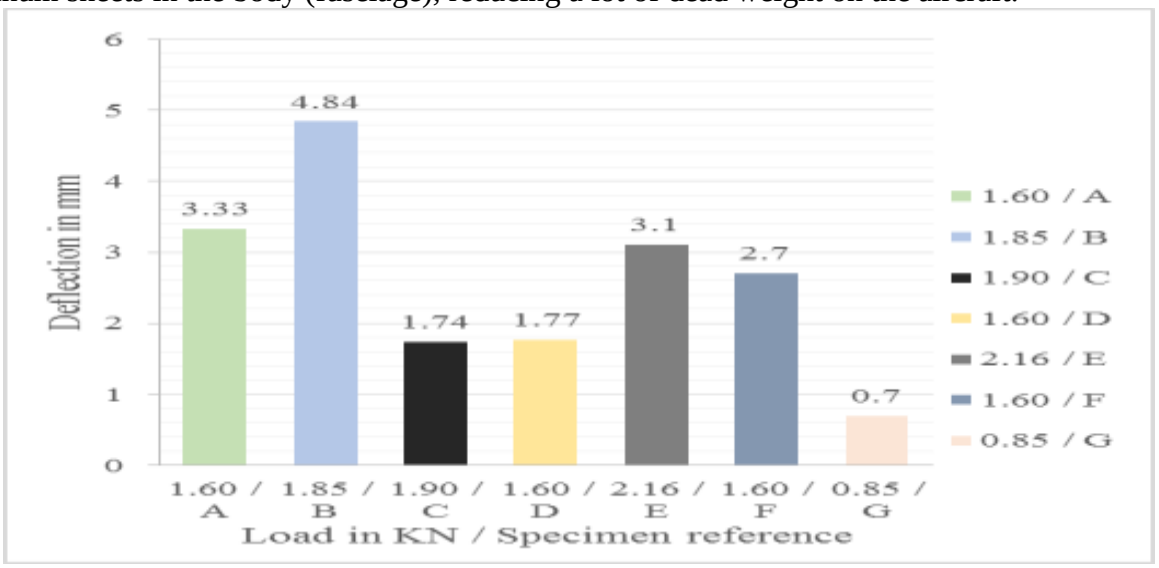

Fig. 1. Load v/s deflection criteria of the polymer nanocomposites specimens.

IV. Field Emission Scanning Electron Microscopy (FESEM)

Figure 2 and Figure 3, shows the FESEM images taken from different angles of the polymer nanocomposite specimen F. Figure 2 with magnification of (a) 1µm, (b) 500nm, (c) 200nm, shows clearly that the nanoparticles embedded in the matrix appear like shiny particles under the influence of a strong electron beam liberated by a field emission source, whereas the other dull matrix are the layers of plain polymer, the fillers are acting as tailoring agents for the holding matrix, more like a bridge formation inducing strength for the holding matrix. Figure 3 shows the surface structure of MWCNT's which appear like shiny particles. The nanofillers interaction with the holding matrix such as dispersion, tailoring of different layers of polymers, interfacial adhesion could be revealed from Figure 2 and Figure 3.

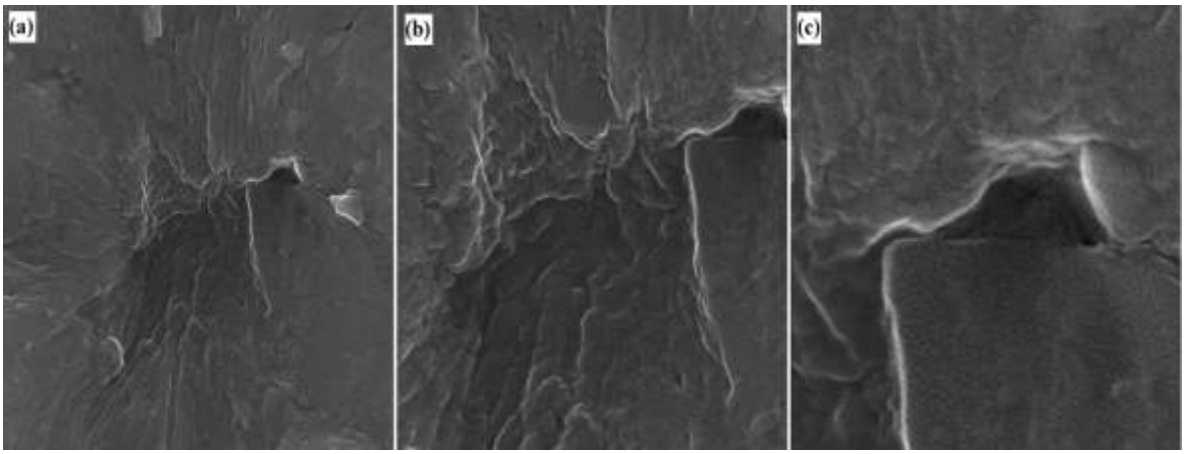

Fig. 2. FESEM images of specimen F with magnification of (a) 1µm, (b) 500nm and (c) 200nm.

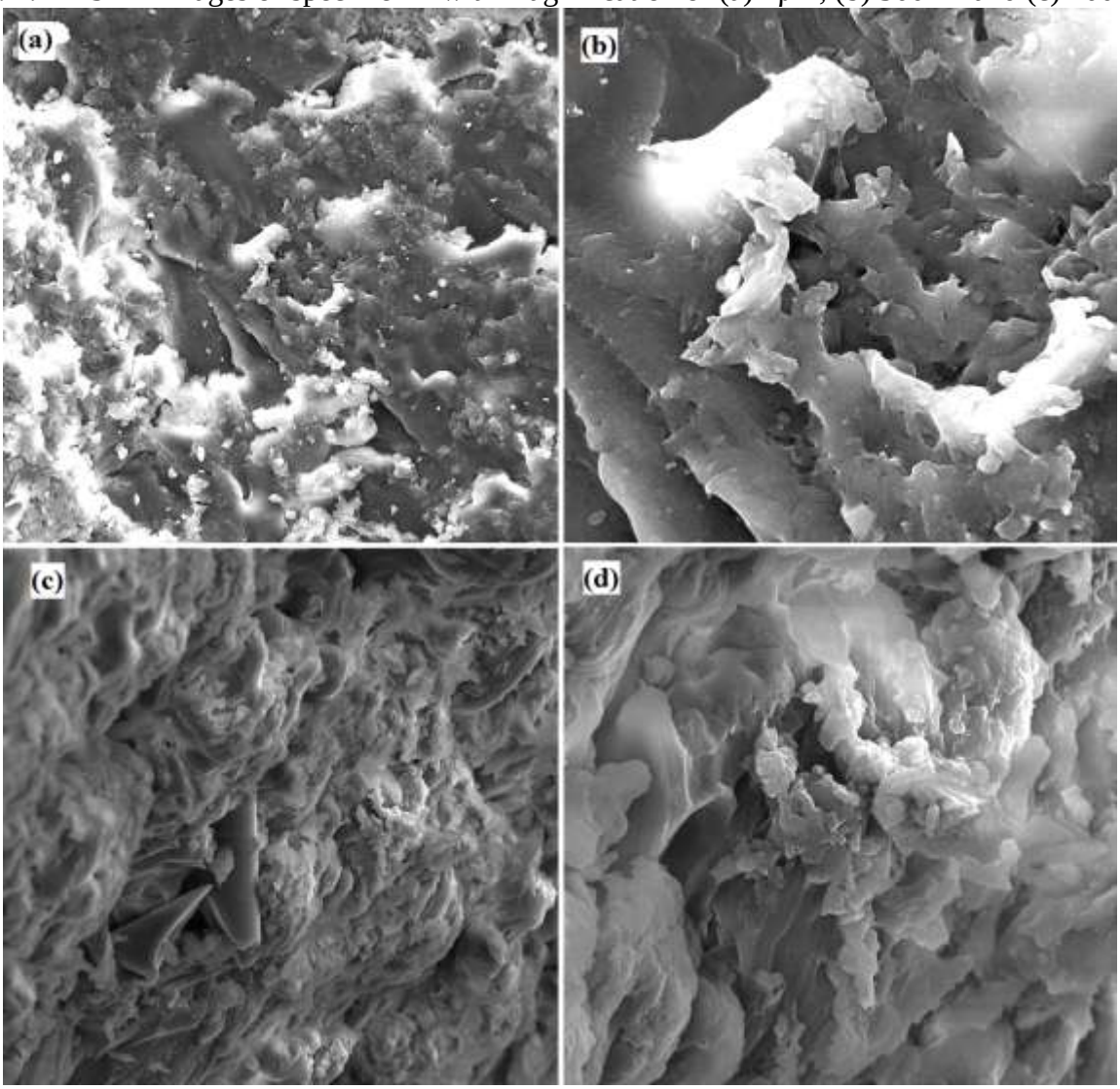

Fig. 3. FESEM images of specimen F from different angles with magnification of (a) 10µm, (b) 2µm, (c) 10µm and (d) 2µm.

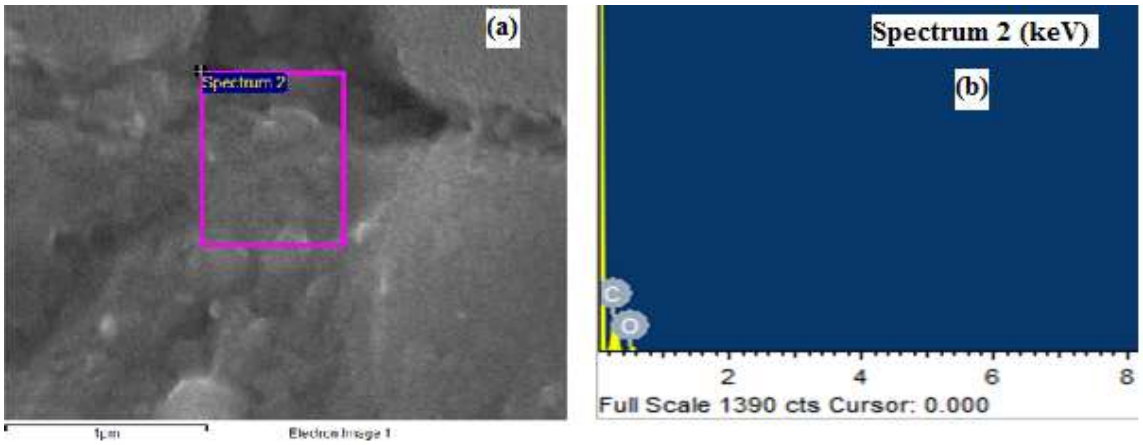

Fig. 4. EDS spectra of nanocomposite specimen F shown in (a) and elemental composition shown in (b).

V. ENERGY DISPERSIVE X-RAY SPECTROSCOPY (EDX OR EDS)

EDS test was carried out to determine the influence of other elemental compositions on the strength parameters of polymer nanocomposites. Figure 4 shows the elemental composition of carbon and oxygen as traces of elements, the presence of these traces does not provide any substantial effects on the desired mechanical properties of polymer nanocomposites, the EDS spectra of FESEM photographs have been explored for the distribution of Nanofillers in the holding matrix. From these EDS spectra, it is verified that the Nano fillers were distributed uniformly in the polymer matrix.

VI. CONCLUSION

The effect of the dispersion of nanoparticles in polymer matrix were studied. A significant change in the glass transition temperature for B & E compositions were observed. A weak interaction for polymer nanocomposites with D & G specimens and no significant interaction in all other cases. As for the epoxy/MWCNT's/CF's nanocomposites there is an increase of 15.64% for specimen B, similarly there is an increase of 34.38% for specimen E. While there was an increase in the ultimate load carrying capacity for B & E as compared to plain polymer, there was no drastic increase with the increase in composition for specimens C with 18.77% increment and F with 0% as compared to plain epoxy, which can be attributed in the case of both MWCNT's and CF's fillers the homogeneous dispersion which resulted in increasing the surface area accessible for stress transfer which was reflected through the increase of ultimate tensile strength, further increase of the compositions of the fillers in the holding matrix led to the decrement of strength this could be due to the rise in viscosity of the holding matrix with increasing filler content making it brittle as observed for specimens D & G, in fact for specimen G there was a huge decrement in the readings tabulated. Strong interfacial adhesion between the holding matrix and fillers can be observed through the Figure 2 and Figure 3, which is further confirmed by EDS results. This study can be proposed as a substitute for various materials in the structural stability of the aircraft, having wide scope in aerospace the industry.

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