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Enhancement of Carbon Fiber/Epoxy Composite Electrical, Optical and Thermal properties by using different types of Nano-Additives.

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Abstract. : The electrical, optical and thermal properties of the carbon fiber/Epoxy composite were studied after the addition of nano-particles to be used in space application. Three different nano-particle (Al_2O_3, MWCNT, and RGO) were used to be dispersed in the epoxy matrix. The optical, thermal and electrical properties were tested by UV-visible Spectroscopy, Photo acoustic spectroscopy (PA)and Keithley 2635A respectively. The results revealed an enhancement in the electrical, optical and thermal properties of epoxy matrix after the addition of nano-particles.

1. INTRODUCTION

Many environmental threats causes the degradation of materials used on the exterior spacecraft surfaces [1].For this reason, It is important to always update and improve existing materials and create new materials with enhanced properties to be use in space applications [2]. Space radiation causes the spacecraft material properties to degrades and this degradation affects the spacecraft lifetime in space. There are two kind of space radiation, particles radiation and electromagnetic radiation[3].

Epoxy resin is widely used in polymer based composites as a matrix material. The reason behind this, is that epoxy matrix contains high chemical, electrical, thermal and mechanical properties[4]. However, the basic thermal conductivity of epoxy is low (0.17–0.21 W/mK) and often exhibits a brittle nature[5]. Therefore Nano-reinforcements such as nano-ceramic, carbon nanotubes, and graphene structures are usually employed in order to enhance the deficiencies in neat epoxies[3],[4].

In 2016,astudy byTetjanaTomaskovaet.al. tested the effect of aluminum oxide nanoparticles on the mechanical and physical properties of epoxy resin. Various weight percentages of2, 4, 6, 8 and10wt. % were added to epoxy resin. The steady-state method, Dielectric strength tests and tensile tests were applied to study the physical and mechanical properties of epoxy/Al_2O_3nanocomposite.The results revealed an enhancement in the thermal and mechanical properties of epoxy resin after the addition of Al_2O_3nanoparticles. The highest increase in thermal and mechanical properties was achieved by 8wt% of Al_2O_3nanoparticles[6].

In 2017, Ganiu B.et.al.studied the effect of reduced graphene oxide(RGO)on the thermal and mechanical properties of epoxy matrix. Different thermal and mechanical behaviors of the epoxy nanocomposites were investigated. The result revealed an outstanding increase in the thermal conductivity when a small amount of RGO was added . An enhancement of~40% compared

with that of the unmodified epoxy polymer was obtained by adding a value of 0.06 weight percentage (wt. %) of RGO. This value represents one of the highest increase in the thermal conductivity per wt. % when adding RGO ever reported[7].

In2019, a study by Tagreed M. Al-Saadiet.al.showed the reinforcement of epoxy resin with different concentration (0.0, 0.02,0.04,and 0.06)of the multi-walled carbon nanotubes (MWCNTs) to fabricate the epoxy/MWCNTs nanocomposites. This research observed the effect of MWCNTson the mechanical, electrical and thermal properties of epoxy matrix. Hardness, electrical properties such as dielectric constant, dielectric loss factor, dielectric strength, electrical conductivity, and thermal properties such as thermal conductivity were studied. The results revealed an enhancement in hardness, thermal and electrical conductivity and break down strength with increasing MWCNTs weight percent. However, the dielectric loss factor and dielectric constant is decreased when increasing the concentration of MWCNTs[8].

In this work, aluminum oxide (Al_2O_3), multi-wall carbon nanotubes (MWCNTs) and reduced graphene oxide (RGO) were dispersed in an epoxy matrix to study their effect on the physical property of epoxy resin. These three nanoparticles were chosen because they showed an enhancement in the physical and mechanical properties of epoxy matrix[[6] − [8]].

2.EXPERIMENTAL WORK

2.1 Material

Epoxy nanocomposites samples were made using biresin® two parts matrix; part A CR82 (resin) and part B CR80-6 (hardener). Three different nanoparticle materials were added to the epoxy matrix.

Table 1summarize different types and characteristics of each nanoparticle used in this research

Nanoparticles	Characteristics
Aluminum oxide (Al_2O_3)	White powder of Gamma- Al_2O_3, with purity of 99.99% and a 0.4 to 1.5 nanometer diameter
Multi-walled carbon nanotubes (MWCNT)	MWCNT's were formed by a high-yield catalytic process based on chemical vapor deposition (CVD) with an outer mean diameter of (8-10 nm) and inner mean diameter (4nm) and length from (5-10 μm). The purity of neat MWCNTs was greater than 90%.
Reduced graphene oxide (RGO) Three different type of reduced graphene oxide were used in this study (G24N, G33C, G270).	1. Sample G24N also called 4NG: It is N-doped reduced graphene oxide with 3D structure. Its atomic composition is 83.3 % C, 13.9 % O and 2.8 % N. It is synthesized by thermal dissociation of PET waste bottles with urea at 800˚C for 5 hr. 2. Sample G33C was prepared as sample 9C [9].but not in the same batch. Its atomic composition is 90.49% C, 2.131% H and 7.379% O. 3. Sample G270: It is an N-doped multilayered graphene nanosheet. Its atomic composition is 89 % C, 7.2 % O and 3.8 % N. The graphene nanosheets are well exfoliated. The doped N has dominated pyloric conformation followed by pyrdinic and lastly graphitic. It is synthesized by hydrothermal treatment of glucose solution under mild synthesis conditions.

2.2. Specimen Preparation

2.2.1 sonication process

Epoxy resin (50g) was mixed with the three different types of nanoparticles (Al_2O_3, RGO and MWCNTs) each type was added at a specified weight percent (1%, 0.3% and 0.5% respectively) in epoxy resin after stirring for 5 minutes at room temperature. The nanoparticles were well dispersed in epoxy resin by using "SONICS VCX750" sonicator for a constant time (1 h) with 9 KHz frequency and 750W power.

2.2.2 Production of nanocomposites sheet

Firstly, about 27 wt. % of hardenerwas added to the mixture of 50g epoxy and nanoparticles.Then using a well waxed glass sheet with a double faced tape border; the epoxy/nanoparticle mixture was rolled into a uniform layer. A carbon fiber fabric layer of

0.4mm thickness was then rolled on the epoxy/ nanoparticle layer. Followed by a second layer of the epoxy/nanoparticle mixture. This process was repeated three times then a layer of foam was added to absorb the excessive resin used in the hand layup process. The whole glass was wrapped with vacuum bag and taped. Finally, the whole sheet was vacuumed with (-1) bar at 45℃ for 24h.The final sheet obtained contained four layers of carbon fiber fabric with 2.4mm thickness.

2.2.3 Experimental methods

2.3.1 Optical Test (UV-visible Spectroscopy (Spectrophotometer (Jasco 670))

A double beam Spectrophotometer (V-670)was used to obtain the optical behavior of the samples by measuring the amount of electromagnetic radiation transferred through a sample as a function of wavelength. The spectrophotometer consists of four parts; a source of electromagnetic radiation, a monochromator, a sample container and a detector.

All samples were cut to thin films of 1cm x 1cm and placed inside the sample container. A tungsten filament lamp was used to provide light with proper wavelengths and intensity. The light passes through the entrance slit of the monochromator. The monochromator produces a beam of radiation consisting of a limited range of wavelengths (200- 2700nm) within a huge spectral region. Then the detector reacts to the intensity of light falling on it by generating an electrical signal (current). The signal is then amplified to an acceptable magnitude to be recorded on the computer.

2.3.2. Thermal Test (Photoacoustic spectroscopy (PA))

Thermal properties of each sample were determined by a laser photo acoustic spectroscopy (Stabilite2017 model 2550) device shown in figure 1. The light beam was obtained from atungsten–halogen lamp (1000 Watt). In the entrance of a mono-chrometer, The light beam wasdirected. From the existing slit, an output beam was mechanically adjust by an optical chopper. Moreover, the output beam was subjected to a sample of (1cm x 1cm) that was attentively mounted inside a PA cell. Then, ahighly sensitive electrical microphone fixed inside the PA cell detects the sound wave initiated from the sample as an acoustic signal.

Two kinds of amplifiers (low noise preamplifier and lock-in amplifier) were used to amplify the PA signal obtained. A personal computer was attached to the system to automatically obtain and analyze data. The PA spectrum is then displayed in a computer system. At last, the PA spectra were justifiedas a function of wavelength by using carbon black absorber for normalization due to the variations in the source intensity. The depth profile analysis, for each sample were achieved byusing 200 mW (514 nm) argon ion laser to record the PA signal amplitude at various chopping frequencies.

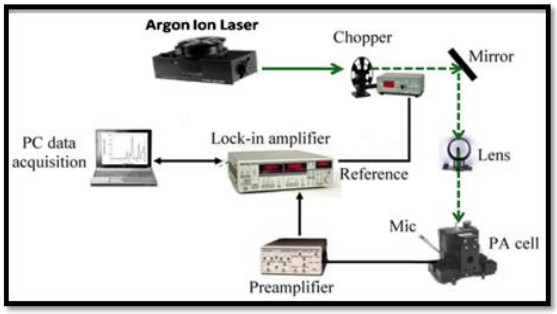

Fig 1 Photoacoustic spectroscopy

2.3.3. Electrical Test

The samples electrical resistances were measured by Keithley 2635A System Source Meter at the National Center for Radiation Research and Technology, Cairo, Egypt. Each sample was cut into small sheet of 1cm x 1cm. The samples were subjected to a current of 1mA and a voltage of 20V. The clamps were connected to positive and negative electrical current. The samples were placed between the clamps that contain a subjected circular area of 12.57mm^2. The electrical conductivity was calculated by

$$\boldsymbol{\sigma = \frac{L}{R*A}} \qquad \text{Equation 1}$$

Where (σ) is the electrical conductivity in S/cm, (L) is the thickness in cm, (R) is the resistance in ohms and (A)is the subjected area in cm^2.

4.RESULTS AND DISCUSSIONS

4.1 Optical test results:

The optical absorption spectra of the neat epoxy and epoxy/nanoparticles were obtained by regular UV-Vis. As shown in graph (1) the range of wavelength was from (200-2700nm) to show the difference types of light absorbed by each sample such as Ultraviolet(200-400nm), Visible light (400nm-700nm), Near infrared (700-1100), Infrared light(1100nm-2700nm). It is easily observed that epoxy matrix and all nanocomposites samples were in the infrared wavelength range. The absorption range for neat epoxy, epoxy/Al_2O_3 and epoxy/G270 nanocomposites begins at absorption peak of

1800nm till 2700nm.This is due to the existence of oxygen and nitrogen that cause a polarity charges on the surface of the sample which facilitate the movement of the infrared light[10], [11]. But epoxy/G33C and epoxy/MWCNTs showed a higher wavelength peak at 2200nm because the charges on the surface are equivalent. The highest wavelength peak was obtained by G24N where it was observed at 2350nm.This could be due to small amount of doped nitrogen used to reduce the graphene oxide as mention in table(1).

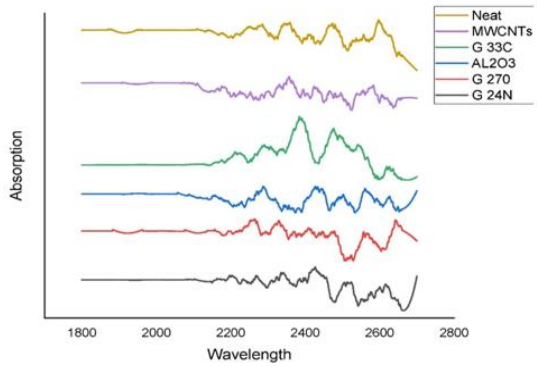

Fig 2optical test for neat epoxy and epoxy nanocomposite

4.2 Thermal test results

The thermal properties of the neat epoxy and epoxy nanocomposites were examined by PA technique, which are of great importance for space application[12]. The sample of 1cm x 1cm sheets was mounted carefully inside the PA cell. From the depth profile analysis, the PA signal amplitude was obtained at various chopping frequencies (f) for each sample.

4.2.1 Thermal parameter measurements

- **Thermal diffusivity (α)**

The thermal diffusivity is a specialthermos-physical parameterthat determine how adequately photonstransfer heat through the sample. Also,it indicates the rate of heat distribution inside the material. Thisratedependsmainly on the thermal conductivity (*k*) of the materialand the energy stored inside the material[13];

$$\alpha = \frac{k}{\rho c} (\mathrm{m^2/s}) \qquad \text{Equation 2}$$

Where:(*c)* is the specific heat capacity and (*ρ)* is the density of the sample.

The thermal diffusivity is experimentally determined by two commonly used methods [14];the first method is known as the transient heat-flow method [15] and the second method is known as the periodic heat-flow method[16]. The PA method used in this research is related to the second method. The sheet of epoxy and epoxy/nanocomposites is mounted carefully inside the PA cell. Moreover, to determine the thermal diffusivity *α,* the PA signal is obtained for various chopping frequencies.

- **Characteristic frequency**

The characteristic frequency (fc)is defined as the critical frequency at which the sample passes from the thermally thin region to the thermally thick region[17]. The thermal diffusivity is computed from the characteristic frequency. The PA signal varies with the thickness and the optical absorption of each sample. Where PA signal varies with chopping frequency of ω^{-1}foroptically opaque and thermally thin samples. However, the PA signal varies with chopping frequency of $\omega^{-3/2}$ for thermally thick samples and when the thermal diffusion length μ_s is smaller than the optical absorption length μ_β. The plots of ln PA amplitude versus the ln f for Epoxy/G33C nanocomposites is drawn in figure (3).

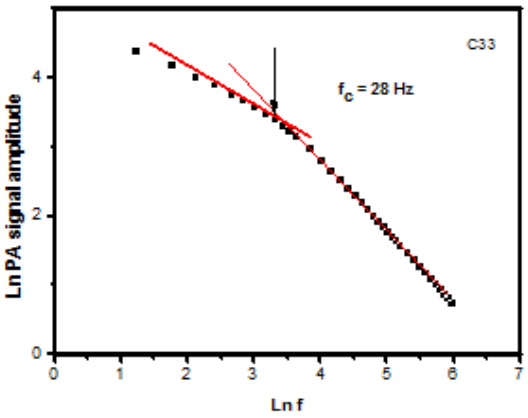

Fig (3): characteristic frequency (fc) of Epoxy/ G33C nanocomposites

The marked change in the slope is where the characteristic frequency (f_c) crossover takes place at which the sample changes from being thermally thin to thermally thick. The thermal diffusivity (α) was then estimated by using this equation[18].

$$\alpha = f_c l^2 \qquad \text{Equation 3}$$

Where:(f_c)isthe characteristic frequency and(*l)* is the thickness of the sample. The values of thermal diffusivity (α) are calculated andwritten in Table (2) for the neat epoxy and epoxy nanocomposites samples. From table (2),the thermal diffusivity(*α)* value for epoxy/carbon fiber (neat epoxy) is 2.4×10^{-7} m^2s^{-1} which is much greater than pure epoxy of 0.5×10^{-7} m^2s^{-1}[19]. Also, the highest thermal diffusivity is obtained by epoxy/MWCNTs of 3.1×10^{-7} m^2s^{-1}.

- **Thermal effusivity (e)**

The thermal effusivity (e) is an important thermal parameter that indicates the surface heating of the substances.The amplitude of the PAsignal "*q*" in case of thermally thick and optically opaque samples is given by:

$$q = \frac{B}{e}\frac{1}{f} \qquad \text{Equation 4}$$

Where: $B = \frac{I_0}{2}\frac{\gamma P_0 \alpha_g^{1/2}}{2\pi l_g T_0}$, ($I_0$) is the incident light intensity, (γ) is the ratio of specificheats, (P_0) is the ambient pressure, (α_g) is the gas thermal diffusivity, (l_g) is the length of the gas column, (T_0) is the ambient temperature, $e = \sqrt{k\rho c}$ is the thermal effusivity of the sample and (f) is the modulation frequency[20]. The different values of the thermal effusivity of Neat epoxy and Epoxy/nanoparticles is obtainedby linear fitting the relation between PA amplitude(q) and (1/f).The values of thermal properties are summarized in table (2).

Table 2Thermal properties of Neat epoxy, Epoxy/nanoparticles

Samples	Thermal diffusivity (α) ($10^{-7}m^2/s$)	Thermal effusivity (e) ($Ws^{1/2}m^{-2}K^{-1}$)	Thermal Conductivity (k) (W/m.k)
Neat	2.4	1080.8	0.52
Al_2O_3	2.85	950.60	0.50
MWCNT	3.1	1141.89	0.63
G24N	1.1	581.35	0.19
G270	1.28	700.37	0.25
G 33C	1.3	793	0.28

As presented in table (2), The thermal effusivity of Neat epoxy is increased after the addition MWCNTs nanoparticles.However, it decreased after the addition of$Al_2O_3$and reduced graphene oxide nanoparticles (G270, G33C, and G24N).

- **Thermal conductivity (k)**

The thermal conductivity is the most important thermal parameterthat can indicate the materials ability to conduct heat. The thermal conductivity is obtained by equation (5) thatrelate the thermal effusivity and diffusivity [18].

$$k = e\sqrt{\alpha} \qquad \text{Equation 5}$$

The thermal conductivity was calculated and tabulated in table (2) by using the determined values of (*e*)and (*α),*

From table (2),The thermal conductivity of carbon fiber/epoxy (neat epoxy) increased to 0.52 $Wm^{-1}K^{-1}$compared to the thermal conductivity of the bulk epoxy of 0.12 $Wm^{-1}K^{-1}$. Also, as expected [8], the highest increase in thermal conductivity is obtained by epoxy/MWCNT snanocomposite by 83% compared to neat epoxy. However, for reduced graphene oxide (G33C,G270, G24N) nanoparticles the thermal conductivity decreased by (54%, 48%37%) in comparison to neat epoxy.

4.3Electrical test results

The electrical resistivity is a measure of the resistance of a given size of a specific material to electrical conduction. Each sample's electrical resistivity was measured by Keithley 2635A SYSTEM Source Meter. Table (3)show the electrical conductivity calculated by

$$\sigma = \frac{L}{R*A} \qquad \text{Equation 6}$$

Where (σ) is the electrical conductivity S/cm, (L) is the thickness in cm, (R) is the resistivity in ohms and (A) subjected area = 0.125664 cm^2.

Table 3 Electrical conductivity of Neat epoxy, Epoxy/nanoparticles

Sample	**Resistivity Ω**	**Electrical conductivityS/cm**
Neat	$0.2076x10^9$	$8.69x10^{-9}$
MWCNT	7433	$2.57x10^{-4}$
Al2O3	633	$3x10^{-3}$
G-270	669	$3.09x10^{-3}$
G-24N	1047	$1.84x10^{-3}$
G-33C	957	$2.08x10^{-3}$

The electrical conductivity of epoxy matrix increased after the addition of nanoparticles. After

the addition of nanoparticles, the neat epoxy changed from an insulating material to a semi-conductive material[21]. The highest increase in electrical conductivity was obtained by epoxy/G-270nano-compositescompared to neat epoxy.The reason behind this enhancement is the reduction of the graphene oxide because as the reduction increases the electrical conductivity increases[22].

CONCLUSION

In this article, the electrical, optical and thermal properties of carbon fiber/Epoxy composite were enhanced by using different types of Nano-additives. The effect of nanoparticles on the electrical and physical properties of carbon fiber/Epoxy composite (neat epoxy) was investigated by UV-visible Spectroscopy, Photoacoustic spectroscopy (PA) and Keithley 2635A.

The optical test showed that the neat epoxy and epoxy/nanoparticles absorption spectra werein the infrared wavelength range. The thermal test indicated that the three thermal parameters diffusivity,effusivity and thermal conductivity were enhanced after the addition of MWCNTs nanoparticles. The electrical test pointed out that after the addition of nanoparticles neat epoxy changed from an insulating material to a semi-conductive material.

This implies that the addition of nanoparticle increases the physical and electrical properties of carbon fiber/epoxy. Also, that the enhancement was much more precise for its optical and electrical properties than its thermal property where more research in this field should be taken in consideration.

REFERENCES

[1] p. K. G. A. K. A.Dever, "chapter 28- Degradation of Spacecraft Materials," *science direct*, pp. 601-645, 2018.

[2] T. V. a. F. I. Jiacheng Wei, "Epoxy/graphene nanocomposites – processing and properties: a review," *Royal Society of CHEMISTRY (RSC Adv.)*, vol. 5, pp. 73510-73524, 24th August 2015.

[3] S. K. M. a. B. Banks, "Degradation of Spacecraft Materials in the Space Environment," *MRS*, vol. 35, no. 1, pp. 20-24, January 2010.

[4] M. R. Z. a. M. Thirmizir, "Comparative study of graphene nanoparticle and multiwall carbon nanotube filled epoxy nanocomposites based on mechanical, thermal and dielectric properties," *science direct*, vol. 119, pp. 57-66, 2017.

[5] M. D. H. L. H. T. Z. D. L. K. I. Anithambigai Permal, "Thermal and mechanical properties of epoxy composite filled with binary particle system of polygonal aluminum oxide and boron nitride platelets," *Journal of Materials Science* , no. 16, 2016.

[6] T. T. a. Š. Bláha, "Effect of Micro-filler of Aluminium Oxide on the Mechanical, Electrical and Thermal Properties of Electrical Insulation Systems," in *18th European Conference on Power Electronics and Applications*, EUROPE, 2016.

[7] G. B. O. a. A. C. Taylor, "A facile way to produce epoxy nanocomposites having excellent thermal conductivity with low contents of reduced graphene oxide," *Journal of Materials Science*, vol. 52, no. 12, p. 7323–7344, Jun 2017.

[8] T. M. A.-S. a. H. A.-J. Abbas, "The effect of Multi Wall Carbon Nanotubes on Some Physical Properties of Epoxy Matrix," in *Phys.Conf.Ser.1003012102*, 2018.

[9] N. A. E. a. H. A.Hamad, "Green synthesis of graphene from recycled PET bottle wastes for use in the adsorption of dyes in aqueous solution," *science Direct*, vol. 145, pp. 57-68, 2017 Nov.

[10] G. a. B.Bhattacharyya, "Microelectrical discharge machining of Ti-6Al-4V: implementation of innovative machining strategies," *science direct*, pp. 99-142, 2017.

[11] A. K. S. a. S. G. Sunol, "handbook of solvents (second Edition)," *Safer Solvent and Processes*, vol. 2, pp. 635-677,679-785, 2014.

[12] C. S. P. B. a. C. S. Alvaro Rodriguez, "Thermal protection system," in *Engineering Innovations*, /www.nasa.gov/centers, pp. 182-199..

[13] D. P. P. Almond, Photothermal science and techniques, London: Chapman & Hall, 1996, 1996.

[14] P. C. a. F. Lepoutre, "Photoacoustic measurements of thermal diffusivity description of the ''drum effect''," *Journal of Applied Physics* , vol. 53, no. 1, 13 October 1998.

[15] G. D. C. a. D. S. B. B. Abeles, "Apparatus for the Measurement of the Thermal Diffusivity of Solids at High Temperatures," *Journal of Applied Physics* , vol. 31, no. 9, 1960.

[16] R. J. J. C. P. B. a. G. L. A. W. J. Parker, "Flash

Method of Determining Thermal Diffusivity, Heat Capacity, and Thermal Conductivity," *Journal of Applied Physics* , vol. 32, no. 9, 1679.

[17] M. T. T. I. Hiroshi Tokukoto, "Photoacoustic Spectra of Semiconductors in the Strong Absorption Region," *Journal of the Physical Society of Japan* , vol. 50, no. 2, pp. 602-605 , 1981.

[18] s. a. k. e. s. n. a. h. t. a. abdelalim, in *journal of physics* , conference series 214, 2010.

[19] J. P.-W. a. J. R. J. Terpiłowski, "A study of thermal diffusivity of carbon-epoxy and glass-epoxy composites using the modified pulse method," in *archives of thermodynamics*, https://www.degruyter.com/, 2014, p. 117–128.

[20] P. P. a. J. Chambron, "Quantitative photoacoustic spectroscopy applied to thermally thick samples," *Journal of Applied Physics,* vol. 51, no. 3, 1980.

[21] M. M. Team, "https://me-mechanicalengineering.com," 2017. [Online]. [Accessed march 2014].

[22] D. A. D. D. P. S. R. Inhwa Jung, "Tunable electrical conductivity of invidual graphene sheets reduced at low temperature," *NANO letters*, vol. 8, no. 12, pp. 4283-4287, 2008.