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Influence of Low Carbon Nanotubes on Mechanical Properties of Araldite LY1564 SP

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ABSTRACT

This paper aims to investigate experimentally the behavior of polymer matrix (Araldite LY 1564 SP) to impact loads through modifying their mechanical properties by incorporating with a low range of Carbon Nanotubes content less than 1%. The tensile and impact tests were applied on the pure epoxy, as well as on carbon nanotubes epoxy composite with various carbon nanotubes ratios. The main results indicated that there is a significant effect of the carbon nanotubes on the polymer matrix composite. Tensile strength has been decreased with respect to the pure epoxy, and on the other hand, the impact resistance and the percentage elongation have been increased for all the percentages of the carbon nanotubes CNT. In addition, it is found that the highest impact resistance and elongation percentage was found at 0.2 wt. % CNT.

Keywords: Carbon Nanotubes; Impact Resistance; Epoxy Matrix Nanotechnology; Araldite LY 1564 SP**.**

1. Introduction

In past three decades there are several applications of composite materials. Those materials have been showed some enhanced properties than pure materials. Carbon nanotubes-polymer composites have a promising performance in many researches, but it does not success in industrial applications yet. To develop the mass production of carbon nanotubes-polymer composites with realistic costs, some researches must be done to evaluate and enhance CNT-polymer composite, because the current production rate is not enough to be competitive with the existing materials used in composite production. The most critical factor affecting the production rate is the production cost factor [1]. The main methods used to produce CNT are laser ablation, solar, Arc discharge, plasma and chemical vapor deposition (CVD). Use CNTs in large quantities is unlikely. Therefore, to increase the production rate of CNT-polymer composite in a reasonable cost, three tasks must be done.

The first task is to study the production methods which used to produce the CNT and choose the most economic and productive methods. Since Iijima [2] discovered carbon nanotubes by arc discharge method, Carbon nanotubes have been focused in many researches, and this is because of its superior properties; excellent mechanical and electrical properties, despite its low density. It also can be used as a good reinforcing material for advanced composite applications. These extraordinary properties provide the opportunities to produce a new type of strong and light weighted materials. It has been discovered two types of CNT, single walled nanotubes (SWNT) and multi-walled nanotubes (MWNT). SWNT is a single graphite sheet wrapped up smoothly into a cylindrical tube, while MWNT appears to be a nest of nanotubes that is arrayed concentrically [3].

Many tests have been made to estimate the properties of carbon nanotubes. The average value of Young's modulus of multi walled carbon nanotubes (MWCTs) is obtained to be 1.8 TPa, and the amplitude of CNTs intrinsic thermal vibrations was measured by transmission electron microscope (TEM) [4]. The average Young's modulus also obtained to be 0.45 TPa and the tensile strength 3.6 GPa of carbon nanotubes (CNTs) synthesized by chemical vapor deposition method [5]. Many other researches showed that multi-walled carbon nanotubes (MWCTs) could be bent and buckled repeatedly under large strain without failure using the tip of an atomic force microscope [6].

Many researches have been exposed a developed techniques to fabricate carbon nanotubes. These techniques mostly used gas phase processes. In 2004, Fabry et al. [7] invented a new technique for the continuous mass production of CNTs known as 3-phase AC plasma technique. However, chemical vapor deposition (CVD) is the simple and economic technique. So that Zhang et al. [8] recently published that, they developed a hydrocarbon CVD method assisted with novel oxygen to resist large-scale ultra-high-growth of SWNTs.

Another researches shows that by modifying and improving CVD techniques, mass production of CNTs can be improved to produce long, uniform, and aligned CNTs with low cost. Iwasaki et al. [9] used an improved CVD technique to produce a millimeter long vertically aligned CNTs. Also Mayya et al. [10] used a modified CVD technique to synthesize a diameter controlled CNTs. It can be noticed that these technique are effective because nanotubes are now available in the market in large quantities (e.g. in Kilograms).

Applications of carbon nanotubes are increasing because of its improved properties. To improve CNTs physical properties, these properties must be accurately evaluated and controlled. Ganesh [11] used low temperature chemical vapor deposition (CVD) technique (<800°C) instead of high temperature techniques, – for example laser ablation and arc discharge – to produce CNTs. Because this technique can accurately control the CNTs alignment, purity, density, length, diameter, and orientation.

After investigating the method of producing the CNT, optimizing the CNT polymer composite will be the 2nd task to be investigated. To accomplish this, CNTs must have high aspect ratios, well purified, well dispersed, aligned in the polymer matrix and have good interfacial properties with matrix. High aspect ratio can be achieved by synthesizing CNTs long in length and small in diameter. However, the length and the diameter must be optimized because if the diameter becomes too small the maximum CNT loading level will be reduced. As well longer CNTs are hard to disperse. Optimizing CNTs cannot be done by simply selecting the best technique, and executing the procedures one after the other. Because if a specific technique is used to fabricate CNT polymer composite, it may affect some properties of CNT.

So that, the manufacturing techniques to fabricate CNT polymer composites must be designed carefully. Schadler et al. [12] fabricated CNT polymer composite, which made from epoxy and 5 wt. % of MWNT, and has an enhancement in the tensile modulus of elasticity from 3.1 GPa to 3.71 GPa, and in the compression modulus from 3.63 GPa to 4.5 GPa. Mora et al. [13] also achieved an enhancement in the tensile properties when fabricating CNT polymer composite. The modulus of elasticity of a composite consists of epoxy with 27 % CNT fibers increased from 1.2 GPa to 18.8 GPa, while the tensile strength increased from 43 MPa to 253 MPa.

The most challenging problem in the fabrication process of CNT polymer composite is the dispersion of the CNT inside the epoxy resin, and this includes separating agglomerated CNT. This process can be performed by ball milling, ultra-sonication, magnetic stirring and calendaring techniques. Ultra-sonication is the most favorable technique to accomplish efficient CNT dispersion in the laboratory scale quantities, but other techniques cannot achieve efficient uniform distribution of the CNT particles into epoxy resins also operates with limited capacity [14].

Enhancing the composite material properties is the 3rd task, but not the last, to increase the productivity of CNT polymer composite. This can be achieved by understanding the mechanisms participated in fabrication methods. This will help to select the appropriate polymers and the CNTs with suitable parameters and thereby optimize the processes. This technique is called post-processing technique. Post-processing technique includes curing the MWNT/epoxy suspension into MWNT/epoxy composite resins, while keeping the uniform distribution of MWNT in place. Various types of post-processing techniques can be used to fabricate the CNT/epoxy composite such as Casting, Hot-pressing, Spin coating, and Electrophoretic deposition (EPD) [15-18].

This research aims to investigate the behavior of polymeric materials and polymer matrix composites for enhanced response to impact loads through modifying their mechanical properties by incorporating different nanoparticles into the polymeric matrix. Since there is an increased demand of low weight high performance materials for impact resistance applications, the research results will be helpful in developing of high performance material forms and processing technologies.

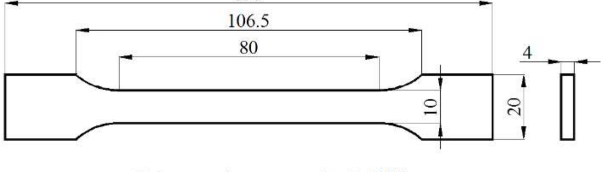
2. Experimental Work

2.1. Material

The materials used in this research: Thermosetting polymer used as a matrix and it has consists of two components (Epoxy resins and it is in the liquid state, and Hardener and it is used for curing), and Different percentages of Carbon nanotubes (from 0.2% to 0.7%), which is used as the reinforcement of the epoxy resins.

2.2. Specimens:

Two different standard types of test specimen groups were fabricated; the first group of specimens for tensile test and the second group of specimens for impact test. The two groups fabricated according to the international standard (ISO 527-2) as shown in Figs.1 (a), (b).



Dimensions are in Millimeter

Fig. 1 (a) Dimensions of the tensile test specimen.

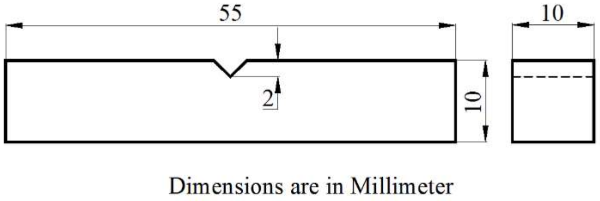


Fig. 1 (b) Dimensions of the impact test specimen.

2.3. Fabrication Procedure

The preparing of composite specimens was adding the carbon nanotubes (CNT) with different percentages to evaluate the most enhancing percentage for the mechanical properties. The chosen percentages of CNTs in this work are 0.2 wt. %, 0.3 wt. %, 0.4 wt. %, 0.5 wt. %, and 0.7 wt. % of carbon nanotubes.

The fabrication of the CNT polymer composite is starting by weighting the material components (the epoxy, the hardener and the CNT) on the digital scale indicated in (Fig. 2) with a weight (wt.) ratio between the epoxy and the hardener 100:34. Then adding the CNT to the epoxy resin and mixing with the magnetic stirrer (Fig. 3) then this mixer was put with a sonicator (Fig. 5) for 2 hours and while the sonication still mixing with the magnetic stirrer at the same time to deagglomerate and homogenize the CNT in the epoxy resin [19].

Fig. 2 the digital scale.

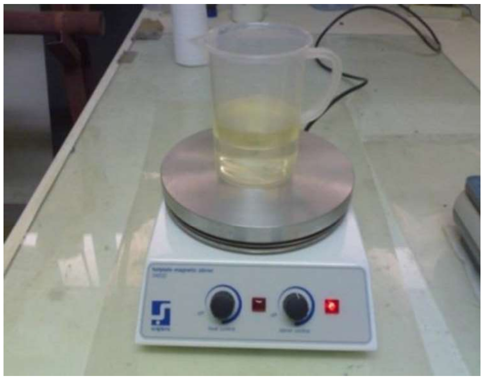


Fig. 3 The magnetic stirrer.

Fig. 4 Oven and vacuum chamber.

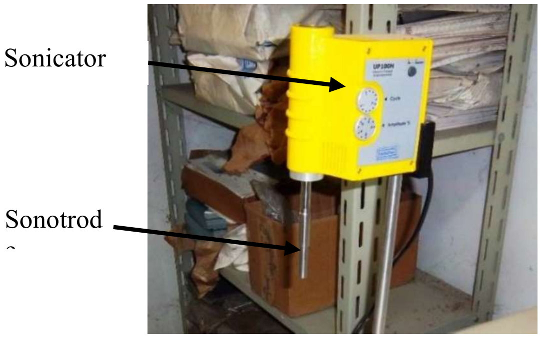


Fig. 5 the sonicator and the sonotrode.

The mixing and sonication process was carried for 2 hours. While mixing and sonicating, the temperature of the resin was raised to 70 ºC by the effect of the Ultrasonic waves produced by the sonicator. This led to the decrease of the viscosity of the resin and resulted in better mixing. After mixing of the CNT, the mixture placed in a vacuum chamber (Fig. 4) for 5 minutes to release any air bubbles, then the mixture was left to cool to 35 ºC after which the hardener was added. If the hardener added to the mixture with a high temperature, it'll be cured so quickly and gets hard before casting it. Therefore, it's mixed thoroughly on the magnetic stirrer for 15 min. The final mix casted in silicon rubber molds then de-molding of specimens after 24 hrs., and finally post curing for 4 hr. at 80º C. Fig. 6, represents the fabricated composite specimens for impact and tensile tests.

Fig. 6 the specimens in the silicon rubber molds.

3. Testing of Specimens

3.1. Tensile Testing

In order to estimate the influence of addition of carbon nanotubes on the ultimate and yield strength, as well as the resistance of the sample to stretch under axial force until it fails, the tensile test specimens were subjected to the standard load condition according to (ISO 527-2), in room temperature 25°C as shown in Fig. 7. The tensile test machine employed in this experiment was The United SFM-100KN Universal Testing Machine as shown in Fig. 7. During the test, an axial loading was applied on the test sample until failure occurs. This test was performed to measure the ultimate and yield strength, modulus of elasticity, yield and tensile and break elongation.

Fig. 7 the specimens before tensile load applied and filled specimen.

3.2. Impact Test

It is the measures and evaluation of the resistance of the specimen to a sudden blow. These tests were performed on specimen size and dimension according to the international standard (ISO 527-2) as shown in Fig. 1 (b). The specimens were designed for Charpy impact test method to investigate the influence of percentage carbon nanotubes into the epoxy on the property of fracture strength. All specimens have dimensions of 55 x 10 x 10 mm according to the ISO 527-2 standard. Through the experimental program, the impact test conducted on 10 identical specimens for each group of CNT. The impact testing machine employed in this test was a computerized Izod/Charpy impact test machine from Zwick/Roell with a 4J pendulum as shown in Fig. 8.

Fig. 8 Impact test machine.

3.3. Scanning Electron Microscope

The dispersion of carbon nanotubes inside the composite evaluated by the Scanning Electron Microscope (SEM). The photos acquired from SEM would be useful to explain the mechanical properties enhancement of composite due to the strengthening of the epoxy by carbon nanotubes.

Fig. 9 JEOL model JXA-840 scanning electron microscope.

The test samples were performed at room temperature 24 °C, and with (SEM), JEOL model JXA-840 scanning electron microscope Fig. 9, which was worked at the accelerating voltage 15 kV, for all the specimens. All the samples were prepared directly from those specimens having the mechanical tests. Moreover, the samples were cleaned with alcohol and coated with a conductive layer i.e. gold by a sputter coater for the conduction of electrons during the SEM process.

4. Results and Discussion

In this section, the mechanical test results; tensile and impact results will be presented and analyzed for the range from 0.2 wt.% to 0.7 wt.% CNTs which is called Low Carbon Nanotubes Content (LCNTs).

4.1. Tensile Properties:

The average values of the yield and ultimate tensile strength, which recorded from the report sheets are plotted against the carbon nanotubes percentage as, indicated in Fig. 10. It is noticed that the results of yield and tensile strengths nearly coincide and the composite strength decreases as carbon nanotubes percentage increases from 0.2 wt. % to 0.5 wt.%. In addition, it is observed that at 0.7 wt. % CNTs the yield and tensile strength begin to increase again.

It is also found that the highest tensile strength is achieved at 0.3 wt. % CNTs with a value of 58.37 MPa while the tensile strength of the pure epoxy is 62.61 MPa. In addition, the highest yield strength is also at 0.3 wt. % CNTs with a value of 58.34 MPa and the yield strength of the pure Epoxy is 62.59 MPa. Therefore, for this group, the trend is that: as the addition of carbon nanotubes contents increases from 0.2 wt. % to 0.7 wt. %, the yield as well as the tensile strength decreases. This results trend may be due to the addition of CNT decreases the ultimate and yield strengths of the LCNTs composites.

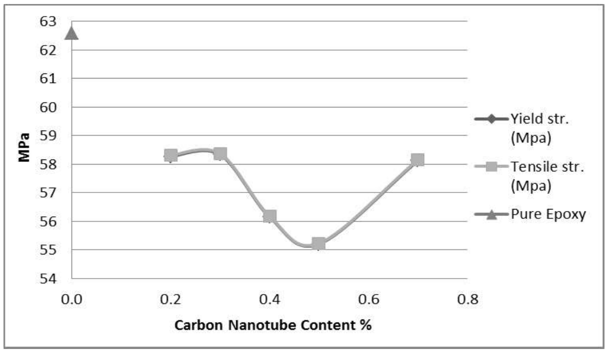


Fig. 10 Results of the yield and tensile strength of low carbon nanotubes composite.

The results of Fig. 11 shows that the elongation percentage also decreases as the CNTs wt. % is increases. It is also noticed that the highest elongation percentage obtained at 0.2 wt. % with a value of 12.95%, and decreases until it reaches its lower value at 0.7 wt. % CNTs with a value of 12.32%, but it's still higher than the elongation percentage of the pure Epoxy which is about 11.26%.

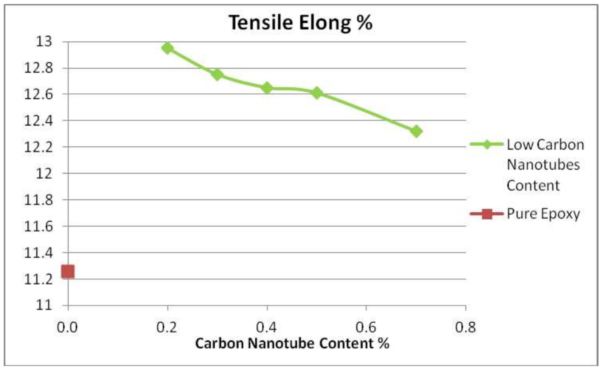


Fig. 11 Results of the elongation percentage of low carbon nanotubes composite.

Therefore, it can be concluded that for all of the addition of low carbon nanotubes contents the elongation percentage, i.e. the ductility of the composite with LCNTs range increases compared to the pure epoxy.

It's also deduced that the addition of carbon nanotubes within the range of LCNTs, the tensile strength is nearly close to the yield strength, and this also agrees with the brittleness of the matrix material i.e. the carbon nanotubes contents in this range don't affect positively the ductility and the tensile behavior.

In order to evaluate the changes in the mechanical properties for the low carbon nanotubes contents (LCNTs) relative to the pure epoxy, the results are illustrated in table 1 for the tensile strength and the tensile elongation percentage.

Table 1 Summary of the tensile properties of Low Carbon Nanotubes contents (LCNTs)

Material	*Nanotubes Content (wt.%)*	*Tensile strength (MPa)*	*Reduction %*	*Tensile Elongation %*	*Improvement%*
(Araldite LY 1564 SP)	*0 %*	*62.61*	*-*	*11.26*	*-*
Low Carbon Nanotubes Content	*0.2 wt.%*	*58.31*	*-6.87 %*	*12.95*	*15.01 %*
	0.3 wt.%	*58.37*	*-6.77 %*	*12.75*	*13.23 %*
	0.4 wt.%	*56.18*	*-10.27 %*	*12.65*	*12.34 %*
	0.5 wt.%	*55.23*	*-11.79 %*	*12.61*	*11.99 %*
	0.7 wt.%	*58.16*	*-7.11 %*	*12.32*	*9.41 %*

As shown in table 1 the tensile strength is reduced and the elongation percentage is improved by adding the CNTs for all percentages of low carbon nanotubes contents (LCNTs) when compared with the pure epoxy.

Also it is noticed that the maximum improvement of the elongation percentage was at 0.2 wt. % CNTs with an improvement percentage of 15%, and the minimum reduction of the tensile strength was at 0.3 wt. % CNTs with a reduction percentage 6.77%, also at 0.2 wt% CNTs the reduction percentage is too close to the 0.3 wt. % which is 6.87%. Therefore, it can be concluded that for the range of (LCNTs) the percentage of carbon nanotubes that can be recommended to improve the elongation percentage with the minimum reduction on the ultimate tensile strength is 0.2 wt. % CNTs with the matrix (Araldite LY 1564 SP).

4.2. Fracture Resistance:

Figure 12 represents the results of impact test for low carbon nanotubes LCNT. Impact toughness shows inverse proportionality to the carbon nanotubes contents. It is found that the impact toughness property for this group in the range of 0.32J to 0.4J. It can be noticed that this group with different percentages has a higher impact resistance than pure Epoxy, which has only 0.3J.

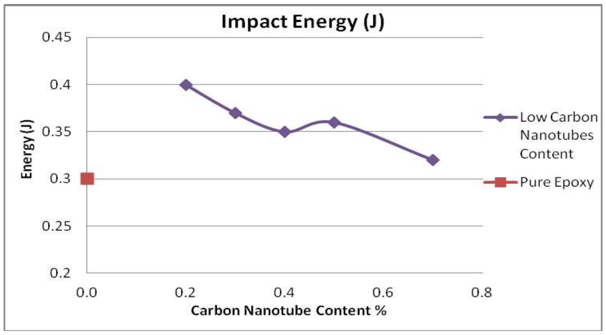


Fig. 12 Results of impact toughness of Low Carbon Nanotubes content composite

The change in impact toughness value for the low carbon nanotubes content relative to the pure epoxy, are illustrated in Table 2.

Table 2 Summary of the impact toughness of Low Carbon Nanotubes content (LCNTs)

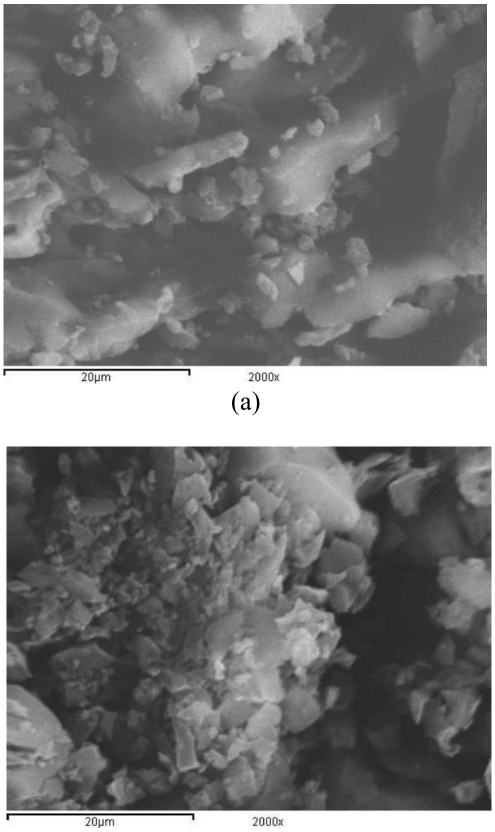
Material	Nanotubes Content (wt %)	Impact Energy (J)	Improvement %
(Araldite LY 1564 SP)	0 %	0.3	-
Low Carbon Nanotubes Content	0.2 wt.%	0.4	33.33 %
	0.3 wt.%	0.37	23.33 %
	0.4 wt.%	0.35	16.67 %
	0.5 wt.%	0.36	20 %
	0.7 wt.%	0.32	6.67 %

As shown in Table 2 the absorption of impact energy is improved by adding the CNTs for all percentages of low carbon nanotubes additions within the experimental range. It's also noticed that the maximum improvement of the impact toughness found at 0.2 wt.% CNTs with an improvement of 33.33%.

Considering the results in Tables 1 and 2, it can be concluded that the recommended carbon nanotubes percentage that can be used to enhance the impact toughness as well as the tensile elongation with the minimum effect on the tensile strength is 0.2 wt. % CNTs for low carbon nanotubes content range. Where, addition of 0.2 wt. % of CNTs leads to achieve the maximum improvement for the elongation percentage with 15.01%, and maximum improvement for the impact toughness 33.33%.

4.3. Analysis of Scanning Electron Microscope

Figures 13 (a) – (b) present the SEM micrographs with high magnification (2000x) on the fracture surface of the CNT-epoxy composite specimens with two different percentages (0.2 wt. %, and 0.7 wt. %). It is noticed that the CNT clusters were formed inside the composite. These clusters showed that there is a poor dispersion of the CNT inside the composite. These agglomerates would affect the load transfer between the epoxy matrix and the CNT, therefore it's may be lowers the tensile and yield strengths for the various percentages of CNT inside the composite, and it raises the ductility because of its higher ductility.



(a)

(b)

Fig. 13 SEM photos of CNT-epoxy composite, (a) 0.2 wt. % CNT-epoxy, (b) 0.7 wt. % CNT-epoxy.

5. Conclusions

The main conclusions of this work are:

1- The addition of carbon nanotubes to the Araldite LY 1564 SP reduces the tensile property within the range from 0.2 to 0.7 wt. % carbon nanotubes.

2- The addition of carbon nanotubes to the Araldite LY 1564 SP improves the fracture property within the range from 0.2 to 0.7 wt. % carbon nanotubes. Also it is concluded that low carbon tubes content has relatively high fracture resistance. It reaches its highest value 0.4J at 0.2 wt. % carbon nanotubes.

3- It can be concluded that the recommended nanotubes percentage that can be used to enhance the impact resistance as well as the tensile elongation with the minimum effect on the tensile strength is 0.2 wt. % CNT for low carbon nanotubes content range.

4- The general trend indicates that the increase of carbon nanotubes contents reduces the elongation percent i.e. reduce the ductility of the composite.

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