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Experimental Studies on Improved CF Composite Material and Study Effect of Addition Fumed Silica

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Abstract. In the present investigation, we used two types of thermoset resins (epoxy resin and phenol formaldehyde resin) with carbon fiber (CF) to produce composite materials. CF/epoxy resin composite and CF/phenolformaldhyde resin composite were fabricated and compared between their mechanical properties as compression, tension and flexural. it was found that mechanical properties of CF/epoxy composite higher than mechanical properties of CF/phenolformaldhyde resin composite such as flexural strength of CF/epoxy resin composite increased by 30 % than flexural strength of CF/phenolformaldhyde resin composite, tensile strength of CF/epoxy resin composite increased by 11.4 % than flexural strength of CF/phenolformaldhyde resin and axial compression strength of CF/epoxy resin composite increased by 14.5 % than flexural strength of CF/phenolformaldhyde resin. In the same time the effect of addition of nano-scale fine particles as fumed silica to CF/epoxy resin composite on mechanical properties was studied. It was found that mechanical properties of CF/epoxy composite decreased after addition of nanoscale particles of fumed silica as flexural strength decreased by 26% due to addition of fumed silica.

Keywords: *carbon fiber; epoxy resin, phenolformaldhyde resin, composites, mechanical properties, nanoparticles, fumed silica.*

I. Introduction

There is an increasing required for advanced materials with enhancement properties to meet new requirements or to replace existing materials. The carbon fibers have a unique combination of outstanding mechanical, physical and chemical properties, such as thermal resistance, high strength, and high modulus [1-3].The carbon fibers reinforced resin matrix composites is widely used in aerospace, marine, and automobile industries during the past few decades due to their good engineering properties such as lower density, high specific strength and stiffness [1-5].Resin matrix of composites based on carbon fiber determines the thermal and chemical resistance of the composite while the carbon fibers provide strength and stiffness[4]. When a composite is subjected to stress, the load is transferred from the matrix to the carbon fibers through the interface and good interfacial bonding is therefore important. It is well known that the fiber matrix adhesion strength plays an essential role on the mechanical properties of fiber reinforced polymer composites because when a load applied to composites, it will be distributed and transferred through fiber/matrix interface [6-9]. A strong bonding promotes the better involvement of more fiber, accordingly increases the strength of composites. However, carbon fibers usually perform a poor adhesion or bonding behavior to polymer matrix due to their chemical inertness and nature of smoothness [6]. In order to improve the bonding properties of carbon fibers, various approaches can be applied, which were classified into oxidative and non-oxidative treatments according to Park and Kim [10]. Composite materials are being preferred more instead of steels and other metals because of their high strength with low specific weight and also because composites have excellent resistance to chemicals, environment and corrosion so can be used in different environments and under various conditions [1-4]. Epoxy resins are considered as high-performance thermosetting resins, which display a unique combination of properties. Epoxy resins are one of the most versatile polymers with uses across an enormously wide variety of industries. They are composed of polymeric molecules that are converted to a solid by a chemical reaction. The ability to be transformed from a low-viscosity liquid (or thermoplastic state) into a tough, hard thermoset is the most valuable

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single property of epoxy resins. An epoxy system physically comprises two essential components: a resin and a curative. The curative causes the chemical reaction, which turns the epoxy resin into a solid, cross linked network of molecules. This polymer is called a thermoset polymer structure with high cohesive strength and adhesion properties because, when cured, it is irreversibly rigid and relatively unaffected by heat. However, the term epoxy can also be used to indicate an epoxy resin thermoplastic or cured state.

Epoxy resin and phenolic resin are industrially very important polymeric materials that have vast application fields. The history of the two materials started before polymer science and polymer chemistry developed. Due to the tremendous efforts of many researchers involved in the materials, resin chemistry has been elucidated and novel approaches for highly functional and high-performance materials are being developed [10]. The increases in the use of the composite materials mean that it is very important and necessary to know their properties and behaviors under working conditions.

Many researches applied on CF composite materials to improve their properties as research of Asma Yasmin, Isaac M. Daniel [11], research of Yuan Xu, Suong Van Hoa [12] and research of Farhana Pervin, Yuanxin Zhou, Vijaya K.Rangari, and Shaik Jeelani [13].

Many studies about the Composites have been carried out. When epoxy resins are reinforced with high strength carbon fibers, the obtained product is used in many commercial, military and structural applications requiring low weight and high strength. They are of relatively low density and they can be formed and tailored to have stacking sequences to produce high strength and stiffness in the directions of high loading [13-14].

In present work two types of thermoset resin used to produce two different types of CF composite materials. The first prepared composite sample was CF/Epoxy resin composite and the second prepared composite sample was CF/phenolformaldhyde resin composite in order to study the effect of the bonding force of the polymeric matrix into the properties of the prepared composite as mechanical properties as tension, compression, and flexural characteristics. We also studied the effect of addition of nanoparticles of fumed silica in to the properties of CF/epoxy resin composites.

Many researches presented several methods to introduce nanoparticle fillers as fumed silica and carbon nanotubes in to the CF/polymer composite system and mainly these methods work in two routes: the first route by mixing the nano particles throughout the matrix, the second approach by introducing the nano particles in to the fiber [15-17]. In our research we mixed the nano particles of fumed silica through the matrix.

II. Experimental Work

A. Materials

The carbon fiber used is PAN carbon fiber made from a polyacrylonitrile precursor has moderate strength; moderate modulus and carbon fiber yarn contains 3000 filaments obtained from Russia. The epoxy resin used in this study is a two component epoxy system consisting of (EPON 828) cured with polyamide (versamide 125) hardener. This two component system obtained from HEXION Company, France .epoxy processed in proportions of 1:1 by weight. Carbon fiber impregnated with phenol formaldehyde resin obtained from Russia. The nano-scale fine particles of fumed silica with particle size equal 40 nm purchased from DUPONT Company, France.

B. Preparation of Epoxy Matrix

Epoxy resin system consists of two parts A (EPON 828) and B hardener (versamide 125), part A was carefully weighed and stochemetric amount of part B was added, then stirring using magnetic stirrer for 30 min with low velocity to prevent air trapping [13]. when addition nano particles of fumed silica to composite material we added it first to part A of polymer and mixed together with stirring in suitable beaker for 10 min for homogeneity, then put in ultrasonic bath sonicator for 30 min to achieve good distribution of silica in epoxy, second step by adding pare B to the mixture and stirring for 10 min, the last by use the matrix contain nano particles with CF to produce composite material [13].

C. Composite Fabrication

Composite material based on CF/epoxy resin and was prepared by hand lay-up technique. Brush and roller were used to help the impregnation of fiber. The epoxy resin was prepared first as in the previous paragraph B. The epoxy was brushed on the surface of CF. the epoxy-brushed fiber tape was carefully stacked up and aligned together layer above layer then compressed adding load 50 Kg over the upper surface and left at room temp for 24 hrs [11]. composite material based on CF/phenolformaldhyde resin were prepared by the same way but differ in the last step because cured at elevated temp so put in a furnace at 150 ^{o}C under pressure 70 bar for 2 hrs.

D. Mechanical Testing

In this research, two types of mechanical testing machines were used. The first test machine is MTS810 Servo-hydraulic material test system with100 KN axial loading was applied to investigate tensile modulus and strength. The second test

machine is RT30Electro-mechanical Alliance test system with 30 KN axial loading applied to measure both flexural and compression strength. The two machine systems were obtained from MTS Company, United States.

1) Compression test.

The compression strength of composite specimen of dimensions [10mm ×10 mm ×20mm] was tested.The test speed was kept const at 2mm/min. Three specimens of each composition were measured and an average value was reported. In the case of composite we measured compression strength in both directions (axial and radial directions) as shown in figure 1.

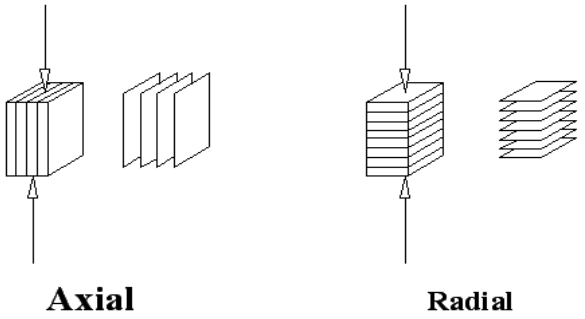

Figure 1. Axial and radial compression specimens for composite material.

2) Flexural test (The three-point bending test).

The Flexural strength is the maximum stress developed when a bar – shaped specimen is subjected as a single beam to a bending force perpendicular to the bar. The Flexural strength of composite specimen of 12.7mm width, 200mm length and thickness according to the number of layers. Three specimens of each composition were measured and an average value was reported.

3) The tensile test.

The tensile strength of composite specimen of 12.7mm width, 203mm length and thickness according to the number of layers. Three specimens of each composition were measured and an average value was reported. The standard shape and dimensions for the tensile test samples and flexural test samples shown in figure 2.

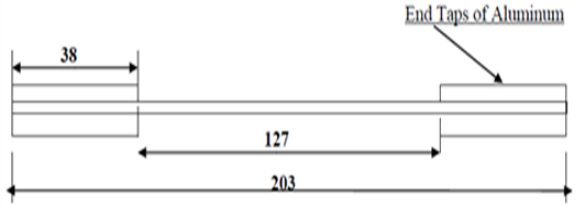

Figure 2. Standard Flat Tensile and flexural specimens.

E. Thermal Conductivity Measurements

Thermal conductivity values are used to measure heat flow through a material according to the apparatus specifications of lee ś disk method used in determination of thermal conductivity of bad conductor, the specified specimens were found to take the form of a thin disc with one side of it is heated by being placed in contact with a metallic steam chamber and the other side is in contact with a cylindrical brass calorimeter which is used for measuring the quantity of heat conducted to it per second as shown in figure 3.

Figure 3. Thermal conductivity measurement apparatus.

The test was carried out according to the following steps:

1. The specimen is placed between the steam chamber and the calorimeter.
2. Heat in the form of steam flows from the higher temperature (steam chamber) to lower one (calorimeter) for a sufficiently long time (45-60 minutes) until the thermometers give constant reading for the temperature of steam chamber and that of the calorimeter denoted by (Θ1 and Θ2) respectively, then the specimen is removed.
3. The calorimeter with steam chamber on it is heated to about 5^0C above the steady temperature Θ2, and then the steam chamber is replaced by the specimens allowing for the calorimeter to cool to a temperature lower 5 ^{0}C below the steady temperature Θ2.

•Rate of heat loss by the calorimeter and specimen is calculated according to the following formula:

$$Q = m*s*(d\Theta/dt) \quad (1)$$

•Rate of conducting of heat = $K*A*(\Theta1 - \Theta2)/X$ (2)

•Thus at steady state: $K*A*(\Theta1 - \Theta2)/X = m*s*(d\Theta/dt)$ (3)

Where:

(Θ1- Θ2)/X ……...Temperature gradient [^{0}C /m]

X…….... Thickness of the specimen[m]

Q……. Rate of heat loss by the calorimeter and specimen [J/sec]

m……..…. Mass of the calorimeter [Kg]
S……..…. Specific heat of calorimeter [J/Kg. ^{0}C]

F. Samples Code and Compositions

The code and composition of the prepared composite samples used in this research illustrated in Table 1.

Table 1. Details of composition of each formulation

Formulation code	Composition
C1	8layers[CF+ epoxy resin]
C2	8 layers[CF+ phenol formaldehyde resin]
C3	8 layers[CF+ epoxy+ 5%silica]

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III. Results and Discussion

A. Particle Size Determinations of Fumed Silica

The particle size of fumed silica can be determined from the figure 4, which show the TEM picture for fumed silica. The particle size of fumed silica was in the range of 35:40 nm as shown in figure 4.

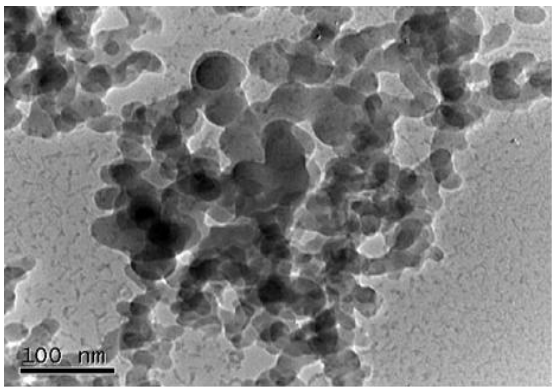

Figure 4. Particle size of fumed silica

B. Mechanical Properties

1) Tensile test result.

The tensile properties of prepared composite materials are shown in figures 5 and figure 6. Figure 5 shows that there are two composite samples based on CF and have the same number of CF layers. The composite sample C1 is based on CF/epoxy resin and the second composite sample C2 is based on CF/phenolformaldhyde resin.

The results show that the tensile strength of composite materials based on CF/epoxy resin is higher than the tensile strength of composite materials based on CF/phenolformaldhyde resin by 11.4 % respectively. This is because the adhesion force of epoxy resin is higher than that of phenolformaldhyde resin, so the composite material based on CF/ epoxy resin matrix has higher tensile strength than that based on CF/phenolformaldhyde resin matrix.

Figure 6 shows the effect of addition 5% fumed silica in to the tensile strength of CF/epoxy resin matrix. The result show that addition of 5% fumed silica decrease the tensile strength by16%,this is because addition of fine particles of fumed silica decrease adhesion surface area between epoxy resin and CF so lead to decrease adhesion force between epoxy resin and CF so respectively decrease mechanical properties as tensile strength.

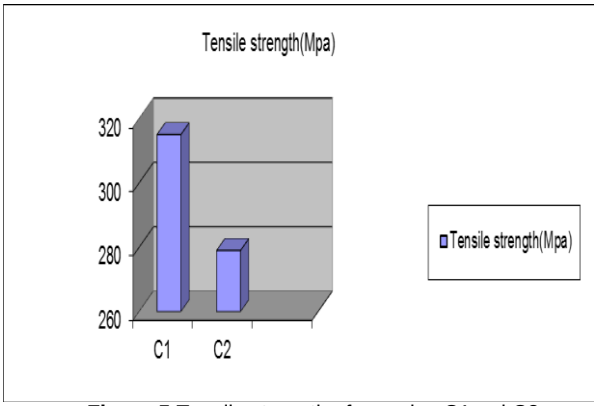

Figure 5. Tensile strength of samples C1and C2

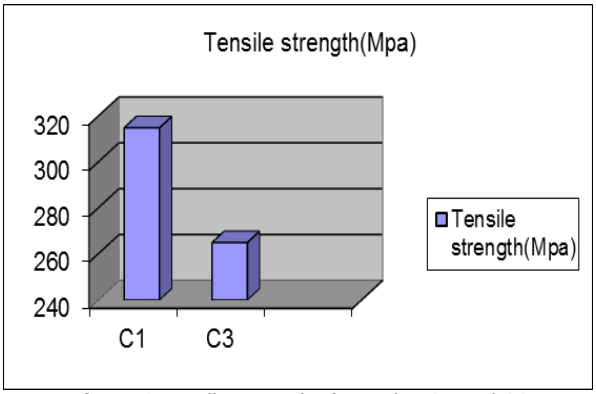

Figure 6. Tensile strength of samples C1 and C3

2) Flexural test result.

The flexural properties of the prepared composite samples are shown in figure7 and figure 8. Figure 7 shows two composite samples based on CF having the same number of layers. The first composite sample is C1 and is based on CF/epoxy resin. The second composite sample C2 is based on CF/phenolformaldhyde resin.

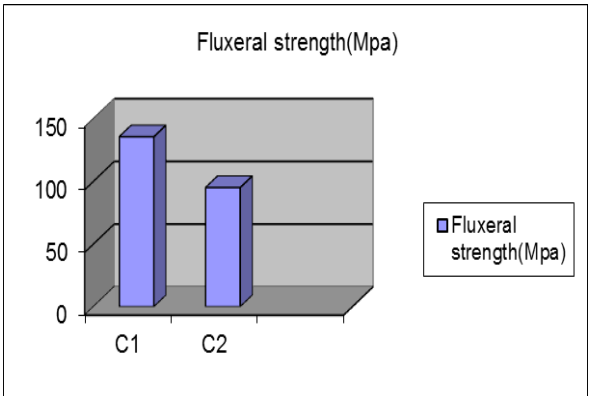

Figure 7. Flexural strength of samples C1 and C2

From figure 7, it can be seen that the flexural strength of composite material based on CF/epoxy resin are higher than those based on CF/phenolformaldhyde resin by 30%. This is because the adhesion force of epoxy resin is higher than that of phenolformaldhyde resin.

Figure 8 shows the effect of addition 5% fumed silica in to the flexural strength of CF/epoxy resin matrix. The result show that addition of 5% fumed silica decrease the flexural strength by 26%,this is because addition of fine particles of fumed silica decrease adhesion surface area between epoxy resin and CF so lead to decrease adhesion force between epoxy resin and CF so respectively decrease mechanical properties as flexural strength.

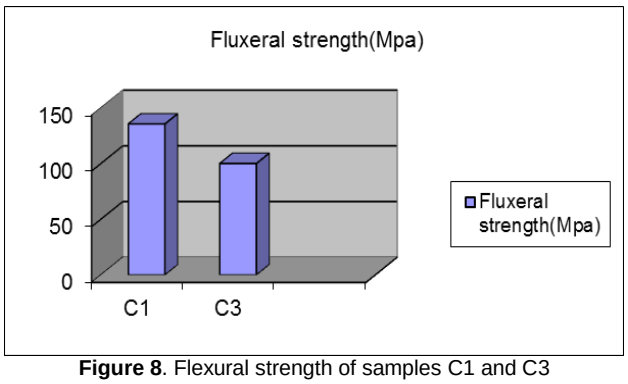

Figure 8. Flexural strength of samples C1 and C3

3) Compression test result

The compression properties of the prepared composite samples are shown in figures 9, 10, 11 and figure 12. Figure 9 and figure 10 show two composite samples based on CF and have the same number of CF layers. The first composite sample C1 is based on CF/epoxy resin and the second composite sample C2 is based on CF/phenolformaldhyde resin.

Figure 9 shows that axial compression strength of C1 is higher than that of C2 by 14.5 %. This is because in the case of axial compression the compression strength depends on adhesion force of resin. The adhesion force of epoxy resin is higher than that of phenolformaldhyde resin.

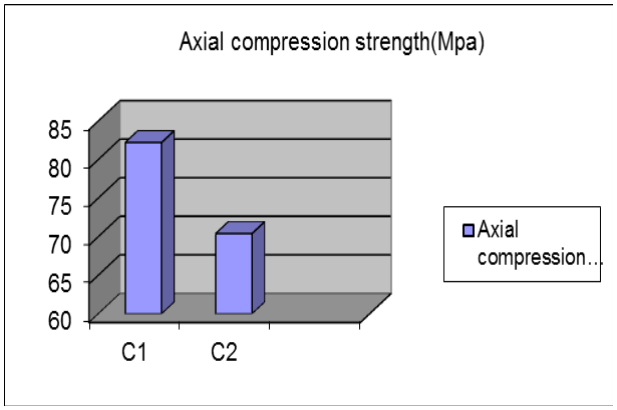

Figure 9. Axial compression strength of samples C1 and C2.

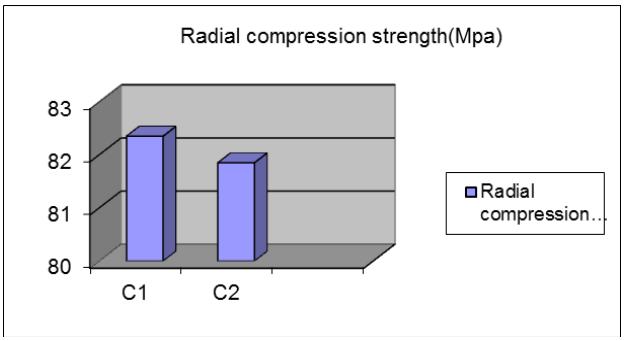

Figure 10. Radial compression strength of samples C1 and C2

Figure 10 shows that radial compression strength of C1 is nearly the same as that of C2. This is because radial compression strength depends on fiber strength, adhesion force of resin type which is the same in the two samples.

Figure 11 and figure 12 show the effect of addition 5% fumed silica in to the axial and radial compression strength of CF/epoxy resin matrix. Figure 11 show that addition of 5% fumed silica decrease the axial compression strength by13%, this is because addition of fine particles of fumed silica decrease adhesion surface area between epoxy resin and CF so lead to decrease adhesion force between epoxy resin and CF so respectively decrease axial compression strength which mainly depend on the adhesion force between fiber and epoxy resin.

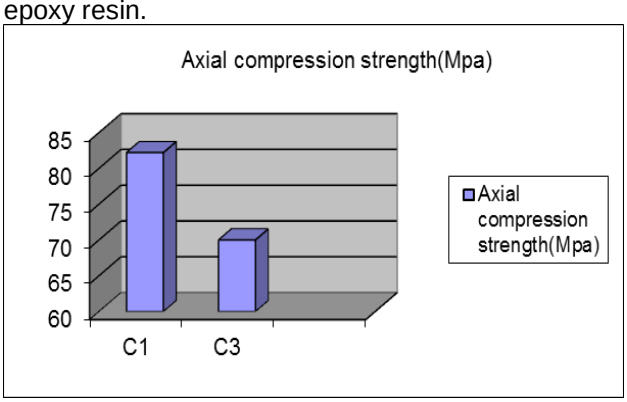

Figure 11. Axial compression strength of samples C1 and C3.

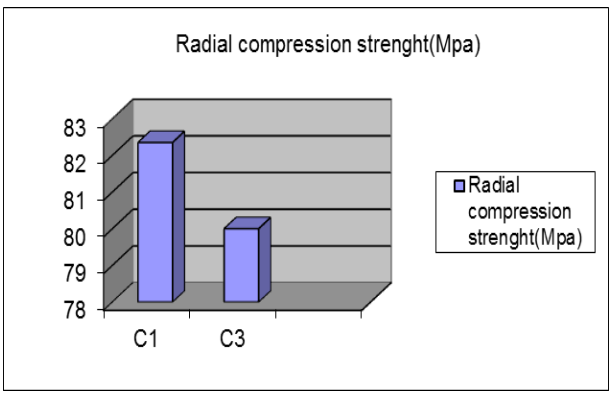

Figure 12. Radial compression strength of samples C1 and C3.

Figure 12 show that addition of 5% fumed silica has no significant difference in radial compression strength; this is because radial compression strength depends on fiber strength, not on the adhesion force of resin which is the same in the two samples.

C. Thermal Conductivity Results

Thermal conductivity results for prepared composite material samples are shown in Table 2. From the results, thermal conductivity values show that the thermal conductivity of C1<C2. The Thermal conductivity of C1 is less than that of C2.the results also show that addition of 5%fumed silica to CF/ epoxy composite slight decrease the thermal conductivity of the sample by 3% as shown in table 2.

Table 2. Thermal conductivity for different prepared composite materials

Characteristics / samples	Thermal conductivity (W/m.^{0}C)
C1	0.1253
C2	0.232
C3	0.122

IV. Conclusions

Resin matrix can be used as one of the most common and effective matrix with carbon fiber to synthesis composite materials based on CF and resin matrix. It was found that as the adhesion bond of the resin matrix increase the mechanical properties of prepared composite increase. Two types of composite materials based on CF were prepared CF/Epoxy resin matrix composite and CF/phenolformaldhyde resin matrix composite. It was found that the mechanical properties of CF/epoxy resin composite higher than that of CF/phenolformaldhyde resin composite due to the higher adhesion force of epoxy resin than phenolformaldhyde resin. For example the tensile strength, flexural strength and axial compression strength of CF/epoxy resin composite is higher than that of CF/phenolformalhyde resin composite by 11.4%,30% and 14.5% respectively. It was also found that the thermal conductivity of CF/epoxy resin composite is lower than that of CF/phenolformaldhyde resin composite. In some cases addition of nanoparticles as second filler in CF/ epoxy composite system increase the mechanical properties of the CF composites, as in case of addition of carbon nanotubes. And in other cases the addition of nanoparticles to CF/ epoxy resin composite decrease the mechanical properties as in our case addition of fumed silica. The effect of the second filler (nanoparticles filler) on the mechanical properties depend on many factors as type of nanoparticles ,shape of the nanoparticles and the amount of nanoparticles added to the composites system.

V. Acknowledgment

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