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Improvement the mechanical and thermal properties of hyper composite materials

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Abstract
In this work; the reinforcement of polyester resin material is conducted with two types, fiber reinforcement and powder reinforcement to produce an isotropic hyper composite materials composed of polyester resin, carbon powder and carbon or glass fibers with different volume fractions. Several tests were achieved to evaluate the mechanical and thermal properties of the manufactured specimens. The effect of adding powder on these properties and the influence of temperature on the modulus of elasticity are studied. The results showed that the modulus of elasticity, thermal conductivity and thermal effusively are increased with increasing volume fraction of carbon powder. It was observed that the hybridization improves the properties of composite materials at a specific volume fraction of carbon powder. The best mechanical and thermal properties for the materials reinforced with glass fibers was occurred in the specimen composed of 50% polyester, 30% glass fibers and 20% carbon powder, while for the material reinforced with carbon fibers it was occurred in the specimen composed of 60% polyester, 30% carbon fibers and 10% carbon powder.

Keywords: Mechanical properties; Composite Materials; Thermal; Hyper.

1. Introduction

The simplest definition of the composite material is a combination of two or more constituents to produce a new material which has different properties as compared with the individual components. All composite materials have two phases, the matrix phase and the filler or reinforcement phase. The matrix phase can be classified into three types: metal, polymer and ceramic while the reinforcement phase can be classified in to fibrous and particulate type [1]. Polymer matrix composite materials are widely used in various applications such as aerospace, marine, sports good, automotive, civil engineering, electronic industry, etc… due to their high stiffness, high specific strength, light weight, low cost, corrosion resistance and high thermal and electrical conductivity [2]. Hybrid composite materials are more advanced composites as compared to fiber reinforced polymer composites. They can have one reinforcing phase with multiple matrix or multiple reinforcing phase with one matrix phase. The physical and mechanical properties of Hybrid composite materials were improved by adding the reinforcing materials and they can be varied by changing the staking sequence and the volume fraction of the reinforcing materials [3]. Many researchers conducted methods of development the physical and thermal properties, Nikhil Gupta et al. [4], studied the properties of hyper composite material consist of fly ash incorporated with glass fiber reinforced epoxy. Very low volume fraction of fly ash was investigated. The results showed that the compressive strength is decreased while the impact strength is increased when adding fly ash. The high cost of the component can be reduced using low cost of available material such as fly ash. Pravuram Panda et al. [5], fabricated hybrid composite materials composed of glass fibers, aluminum nitride powder reinforced epoxy resin and investigated their electrical and thermal properties. The results showed increasing in the thermal conductivity with increasing percentage of aluminum nitride powder. The distribution of the powder and the voids in composite material were observed by using scanning electron microscopy studied. T. D. Jaganntha and G. Harish [6], determined tensile strength, ductility, hardness, peak load and the tensile properties of hyper composite material consists of carbon and glass fiber reinforced the epoxy resin. It was observed that these mechanical properties are improved when the contents of the fibers are increased in the matrix of material. Hakim S. Soltan Aljibory et al. [7], studied dielectric and thermal diffusivity properties of composite material prepared using hand lay-up method with different type of fibers. Thermal diffusivity was evaluated by photoflash method while dielectric loss, thermal conductivity and dielectric constant were evaluated by impedance analyzer technique. It was observed that composite material composed of glass fiber or carbon fibers with epoxy has thermal diffusivity and dielectric properties lower than hybrid composite material. In addition to, the many researches presented the studding of mechanical properties, dynamic behavior and buckling behavior of hyper composite structure are presented by Muhannad Al-Waily, where, at 2012, [8], presented study of the mechanical properties and vibration of hyper composite beam by theoretical and numerical techniques, and, in 2013 [9], presented study of mechanical properties and vibration behavior of isotropic hyper composite materials plate structure, after that, at 2014 [10,11], presented the theoretical and numerical study of mechanical properties and vibration behavior of orthotropic hyper composite plate, [10], and beam, [11], structure. Then, at 2015 [12], presented the experimental investigation of mechanical properties and vibration behavior of isotropic hyper composite plate structure. Also, at same year [13, 14], presented theoretical and numerical investigation for buckling behavior of isotropic, [13], and orthotropic, [14], hyper composite materials plate structure. Finally, in 2016 [15], presented experimentally the effect of Date Palm Nuts Powder reinforcement effect on the mechanical properties and vibration of hyper composite materials plate. Also, at same year [16], was presented experimental investigation the effect of boundary conditions on the natural frequency of isotropic hyper composite plate structure.

The aim of this study is to prepare hyper composite materials composed of unsaturated polyester resin reinforced by glass fiber and carbon powder for the first group of specimens and reinforced by carbon fiber instead of glass fiber for the second group with different volume fractions. The study also includes the investigation of the mechanical and thermal properties of the prepared hyper composite materials and studying the effect of temperature on the modulus of elasticity.

2. Experimental work

2.1 Preparation of mold and manufacturing of tests samples

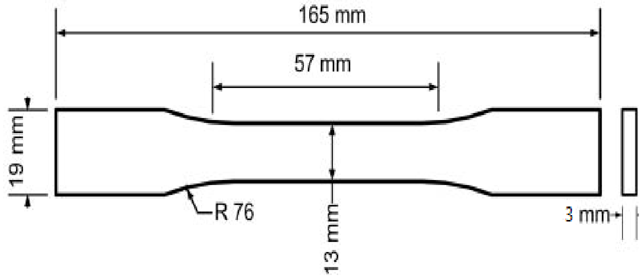
The mold is manufactured of wood and glass so as to make the samples with the desired dimensions. Then the mold is prepared using wax to insure the clean and smooth facing and also to easy the process of sample removal. There are several methods to manufacture the composite structure. There are advantages and disadvantages for each one of them. It has been using the hand lay out method to prepare the models and samples because it is the simplest procedure to use and the way by which to obtain the samples in different shapes and sizes. In this research twenty-two samples made of polyester reinforced with different volume fraction of carbon or glass fibers and carbon powder were manufactured for each test.

2.2 Tensile test

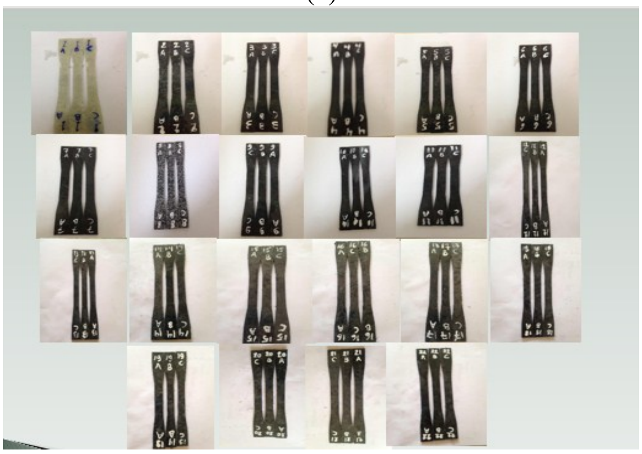
According to ASTM D638-03 the samples were cut up from the manufactured plate; 165 mm length, 19 mm width, 3mm thickness (three specimens for each volume fraction) as shown in Figure 1a This test is done in Materials Engineering Department / University of Technology. The tensile test machine is shown in Figure 1b. The manufactured specimens are shown in the Figure 1c. The specimen was put in this machine and then pulled hydraulically with strain rate (0.5 mm/min). The results of this test are listed in Table 1 and Table 2.

2.3 Thermo-mechanical analyzer (TMA) test

TMA is a technique used to measure the change in the dimensions of sample (length or volume) as a function of temperature. This technique is widely used to test various types of materials such as polymers, metal, ceramic, glass and fiber etc. in this work it was used to evaluate the Young Modulus and coefficient of thermal expansion as a function of temperature and the value of glass transition temperature Tg is determined. The device, the dimensions of sample and the manufacturing sample are shown in Figure 2.



(a)



(c)

(b)

Figure 1. (a) Dimensions of tensile test specimen, (b) tensile test machine, (c) manufactured specimens.

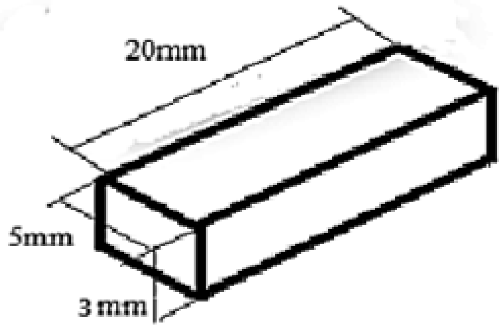


Figure 2. Thermo-mechanical Analyzer (TMA).

2.4 Thermal conductivity test

TCI is a device used to measure the thermal conductivity and thermal effusively of materials. It can be used for various materials such as powder, liquid, solid and pastes and gives the result in a short time, when compared with other devices. The device, the dimensions of sample and the manufactured sample are shown in Figure 3.

The method of preparing and manufacturing the samples is represented in the following steps:

- Weighing the polyester, E-glass fiber, carbon fibers and carbon powder according to volume fraction using the delicate balance. Figure 4a.
- Painting the mold with wax and the weighted material of unsaturated polyester is mixed with the hardener of (2gm) for each (100gm) of resin and mixed continuously and slowly using the glass rod to avoid bubbles during the mixing process which is done at room temperature. During this stage carbon powder are added to the mix partially and the temperature of the mixture is increased which is a guide on start the process of interaction, it is very important to have a good mixture viscosity to protect the particles of sedimentation resulting from heterogeneity of mixture, which leads to a material conglomerate after hardening. Figure 4b.

- The liquid mix is casted in the mold and a layer of fiber is put on the mix surface. To ensure immersion fibers in resin they are compressed using a special brush. Add the mixture and the remaining fiber with the same previous step. Figure 4c.
- The mold is placed on an electric vibrator to remove the air bubbles from the sample (if there are any) as well as to ensure the penetration of the matrix material in all parts of the template.
- A heavy weight is applied on the cover of mold and for the purpose of completing the solidification process a sample left in the mold for a period of (24-6) hours at room temperature. We obtained to final composite plate. Figure 4d.
- The cutting processes for the hybrid composite materials plate using CNC machine are conducted to obtain the final shape of samples.

For the purpose of calculating the volume fraction of matrix and reinforcement materials apply the following equations: $V_r = \upsilon_r / \upsilon_c\ 100\%$, $V_m = \upsilon_m / \upsilon_c\ 100\%$.
Where:
V_r, V_m : Volume fraction of reinforcement and matrix material
υ_r, υ_m , υ_c : Volume of reinforcement, matrix material and composite material.

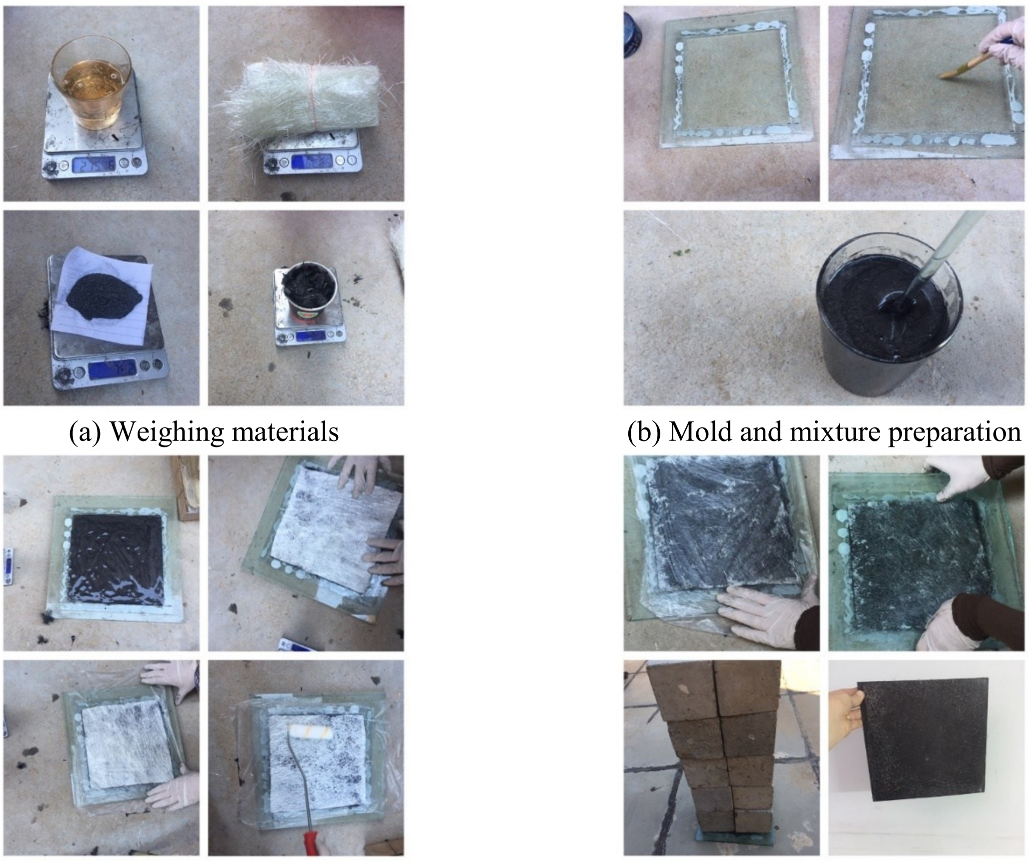
Figure 3. Thermo-conductivity Analyzer test (TCI).

3. Results and discussion

The results of hyper composite materials included the experimental results of mechanical and thermal properties of these materials which composed of chopped glass fiber or carbon fibers, carbon powder and polyester resin with different volume fraction are listed in Table 1 and Table 2. In addition, the effect of temperature on modulus of elasticity is evaluated. Figure 5 shows the effect of adding powder on the modulus of elasticity of the specimens consist of 30%, 20% and 10% fibers. It is clear that the addition of powder to the composite material increases the value of Young 's Modulus for the specimen consist of 30% glass fibers but decreases it for the specimen consist of 20% glass fibers while for specimens consist of carbon fibers it is clear that young's modulus is increased then decreased with increasing of volume fraction of powder for all percentage of carbon fibers These behaviors are happened because of the carbon powder has high value of tensile strength and flexibility if compared with the glass fiber، as well as randomly distributed in the polyester material and ease of penetration of matrix material in these powder and fiber creates a complete interface between the matrix and reinforcement material. But when the value of volume fraction of powder is increased, it leads to reduce in the value of young modulus because of the difficulty of penetration of matrix material in powder and fiber which leads to the weakening of the interrelationship between matrix and fiber, thus reducing the efficiency of carrying the applied load on the composite plate This behavior is the same in the ref. [17]. Figure 6 shows the effect of adding powder on the thermal conductivity of the specimens consist of 30%, 20%, 10% fibers. Also, the addition of powder to the composite material increases thermal conductivity for all specimens except for the specimen composed of 40% carbon powder, it is decreased. Figure 7 shows the effect of adding powder on the effusively of the specimens consist of 30%, 20% and 10% fibers. The figure shows that the effusively is increased with increasing the volume fraction of carbon powder for all specimens except that for the specimen composed of 40% carbon powder is decreased.

The reason of increasing in the thermal conductivity and effusivity that carbon powder has high value of these properties. This behavior is the same in the ref. [18]. Figure 8 shows the effect of adding carbon powder on the thermal expansion of the specimens consist of 30%, 20% and 10% fibers. The results also indicate that the increasing of the volume fraction of carbon fiber leads to a decreasing then increasing in the thermal expansion for all specimens composed of carbon fibers while it is increased then decreased for specimens composed of glass fibers. This behavior occurred due to that the increasing in the volume fraction of the powder leads to decrease the cross linkage for the material and facilitate the crack movement which caused the loosening of the bonds between the molecular of the material. A similar behavior was happened in the ref. [19]. Figure 9 shows the effect of adding carbon powder on the glass transition of the specimens consist of 30%, 20% and 10% fibers. The glass transition temperature is increased then decreased with increasing volume fraction of carbon powder for all specimens except for the specimen composed of 20% glass fibers. The effect of replacing fibers with powder on the Young Modulus, thermal conductivity, effusively, thermal expansion and glass transition are presented in Figures 10-14 for the specimens composed of 50%, 60% and 70% polyester resin. It is clear that the increasing in percentage of powder instead of fibers increases the thermal conductivity, effusively and thermal expansion, while the Young Modulus and glass transition for the specimens composed of carbon fibers are decreased. For the specimens composed of glass fibers, the increasing in percentage of powder instead of fibers increase the thermal conductivity and effusively and then decrease these values except for the specimen composed of 70% polyester, they are increased for all percentage. It is observed that increasing in percentage of powder instead of fibers increases the thermal expansion.

The Young Modulus and glass transition temperature are increased then decreased due to this effect. The effect of temperature on Young 's Modulus for all manufactured specimens is presented in the Figures 15 and 16. It is clear that increasing temperature leads to a decrease Young's Modulus. The decrease in the value of the young modulus may be due to the fact that increasing the temperature of the material leads to the weakness of the molecular chains of the matrix material and thus becomes soft and occurs a great strain leading to that decrease. The same behavior of the young modulus decrease when the temperature increase occurred in the ref. [20].



(a) Weighing materials (b) Mold and mixture preparation

(c) Putting the fibers on the mixture (d) Pressing the cover mold

Figure 4. The steps of manufacturing the hyper composite plates.

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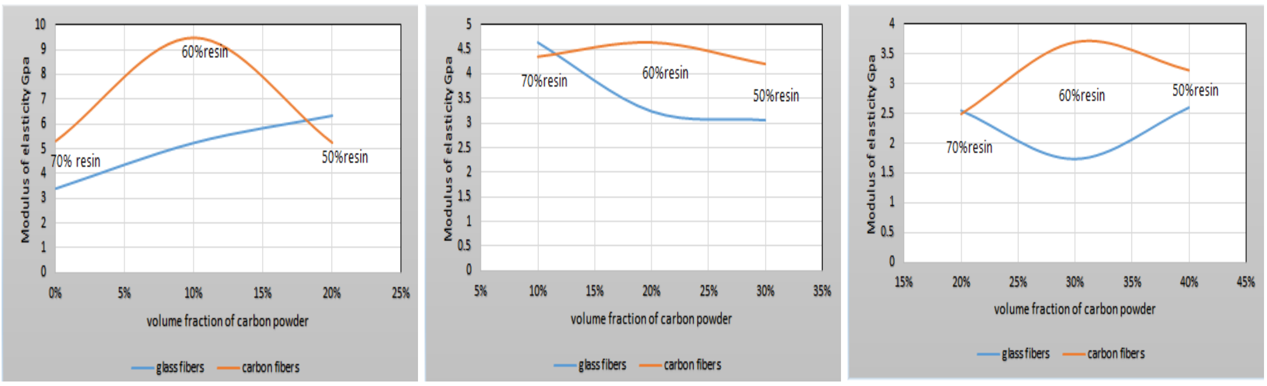
Table 1. Mechanical and thermal properties of the manufactured specimens with glass reinforcement fiber.

Volume fraction of resin	Volume fraction of reinforcement	Volume fraction of fiber	Volume fraction of carbon powder	Hyper composite combined of glass fiber, carbon powder and polyester resin							
				E1	E2	E3	E_{ave} (Gpa)	K W/m.C	ά $W.s^{1/2}/m^2.k$	α 10^{-6}/C	Tg (°C)
70	30	30	0	3.4	3.34	3.46	3.4	0.295	661	17.23	82.5
		25	5	4.2	4.05	4.29	4.18	0.34	709	18	86.6
		20	10	4.5	4.8	4.65	4.65	0.391	756	21.89	95.4
		10	20	2.5	2.6	-	2.55	0.461	836.4	22	88.8
60	40	30	10	5.4	5.2	5.18	5.26	0.397	769	23.45	98.1
		20	20	3.1	3.3	3.35	3.25	0.586	961	26.65	90
		10	30	1.52	1.9	1.78	1.73	0.433	808	27.1	88.8
50	50	40	10	5.64	5.45	5.5	5.53	0.439	827	12.84	91.5
		30	20	6.4	6.31	6.37	6.36	0.491	866.7	16.34	95
		20	30	3	3.11	3.1	3.07	0.679	1049	19.34	86
		10	40	2.55	2.75	2.5	2.6	0.616	989.7	21.32	80

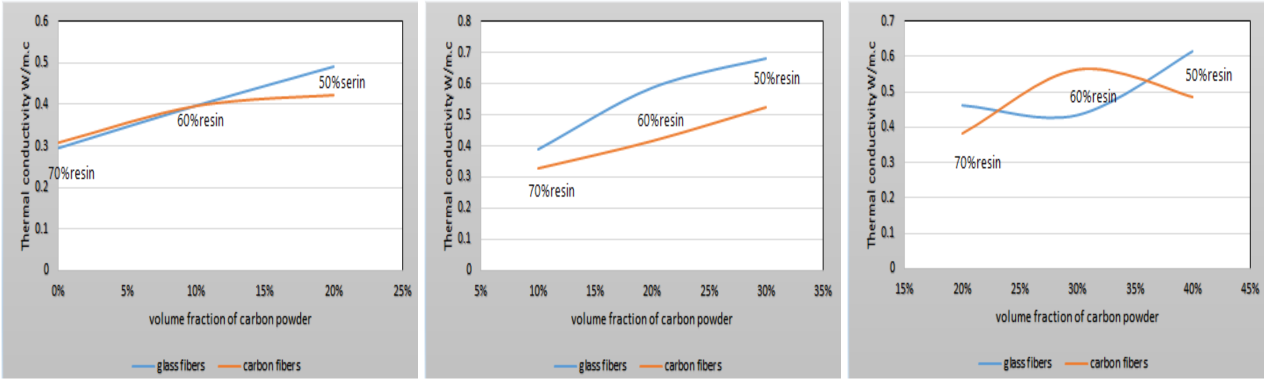
Table 2. Mechanical and thermal properties of the manufactured specimens with carbon reinforcement fiber.

Volume fraction of resin	Volume fraction of reinforcement	Volume fraction of fiber	Volume fraction of carbon powder	Hyper composite combined of carbon fiber, carbon powder and polyester resin							
				E1	E2	E3	E_{ave} (Gpa)	K W/m.C	ά $W.s^{1/2}/m^2.k$	α 10^{-6}/C	Tg (°C)
70	30	30	0	5.27	5.3	5.42	5.33	0.308	628.5	9.56	96
		25	5	4.76	4.9	4.8	4.82	0.319	679.7	10.55	84
		20	10	4.29	4.2	4.56	4.35	0.33	696	12.64	80
		10	20	2.48	-	2.52	2.5	0.381	755.3	15.72	78
60	40	30	10	9.24	9.6	9.63	9.49	0.296	662	6.14	120
		20	20	6.44	6.58	6.36	4.64	0.417	791.4	8.46	90
		10	30	3.59	3.65	3.86	3.7	0.563	938.8	9.25	83
50	50	40	10	8.77	8.48	8.55	8.6	0.338	707	5.8	108
		30	20	5.29	5.23	-	5.26	0.422	796	6	90
		20	30	4.17	4.23	4.2	4.2	0.524	900	9.34	84
		10	40	3.16	3.33	3.2	3.23	0.485	850.3	11.14	78



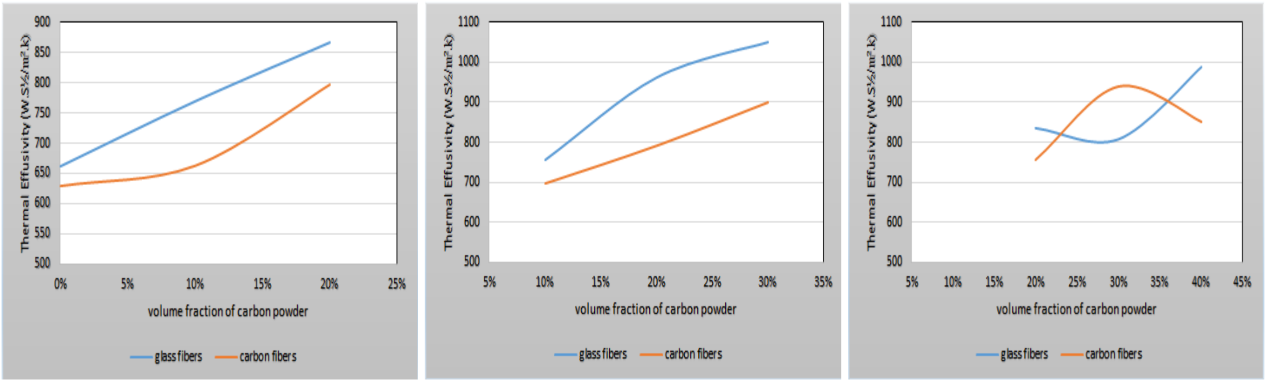
30% fibers 20% fibers 10% fibers

Figure 5. The effect of adding carbon powder on the modulus of elasticity.



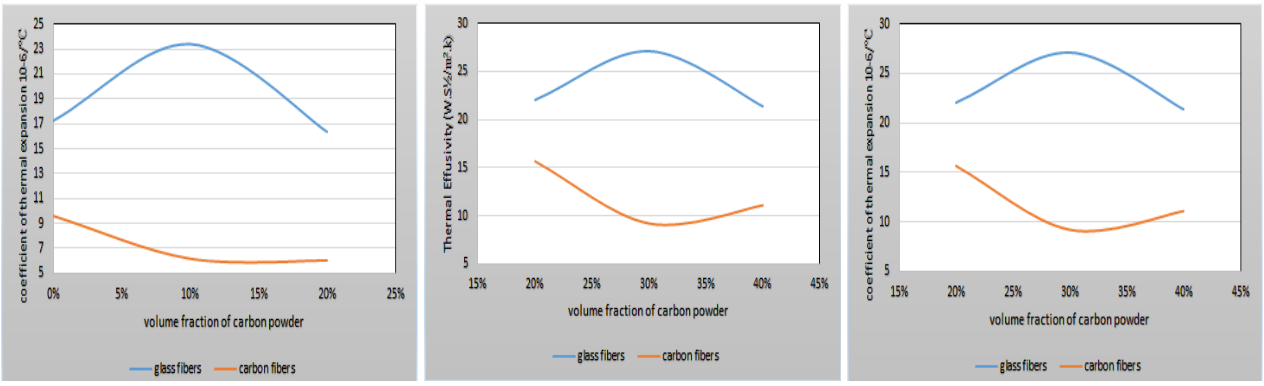
30% fibers 20% fibers 10% fibers

Figure 6. The effect of adding carbon powder on the thermal conductivity.



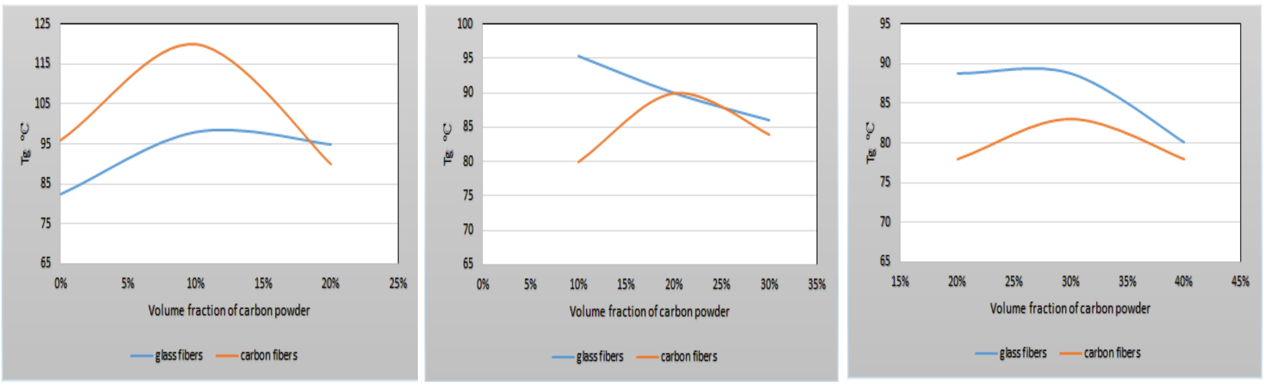
30% fibers 20% fibers 10% fibers

Figure 7. The effect of adding carbon powder on the thermal effusivity.



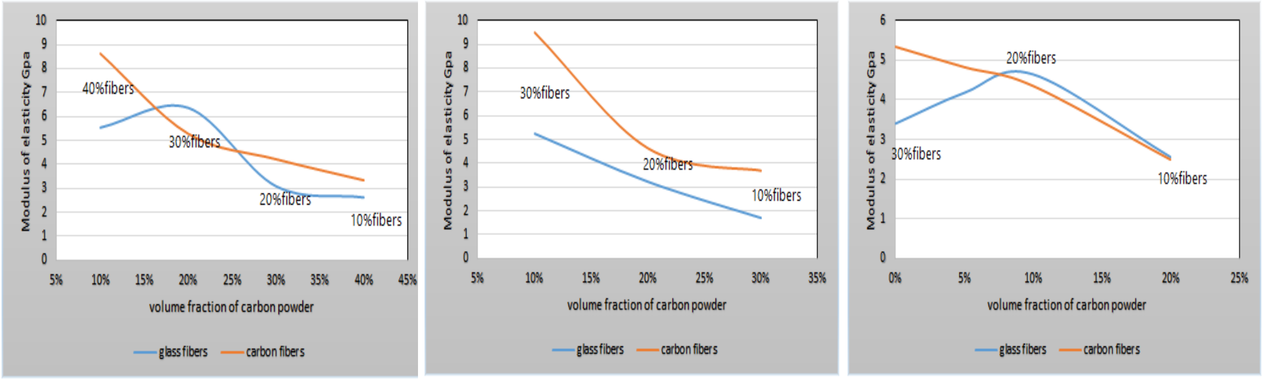
30% fibers 20% fibers 10% fibers

Figure 8. The effect of adding carbon powder on the thermal expansion.



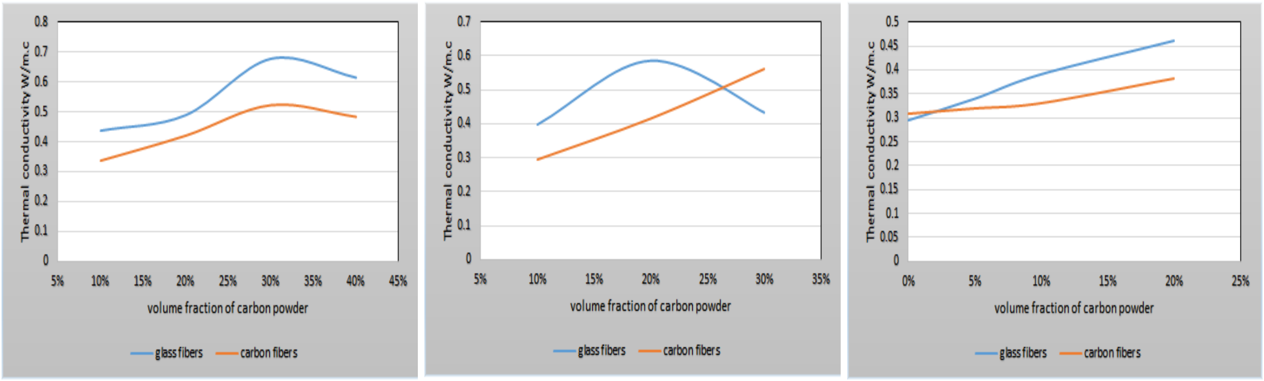
30% fibers 20% fibers 10% fibers

Figure 9. The effect of adding carbon powder on the glass transition.



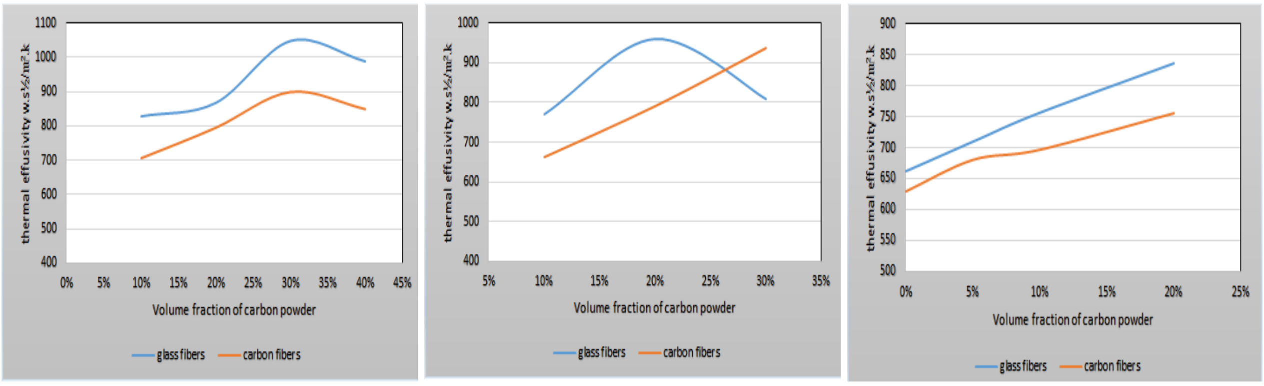
50% fibers 60% fibers 70% fibers

Figure 10. The effect of replacing fiber with powder on the young s' modulus.



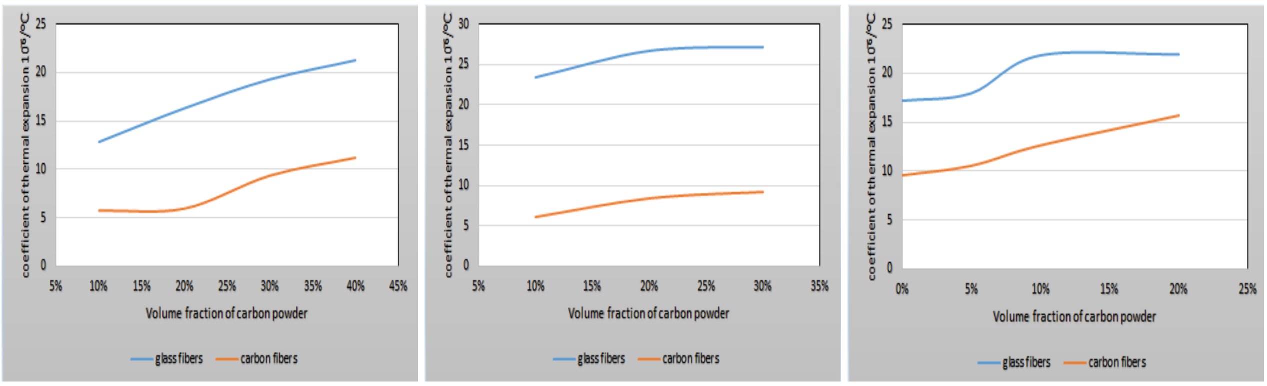
50% fibers 60% fibers 70% fibers

Figure 11. The effect of replacing fiber with powder on the thermal conductivity.



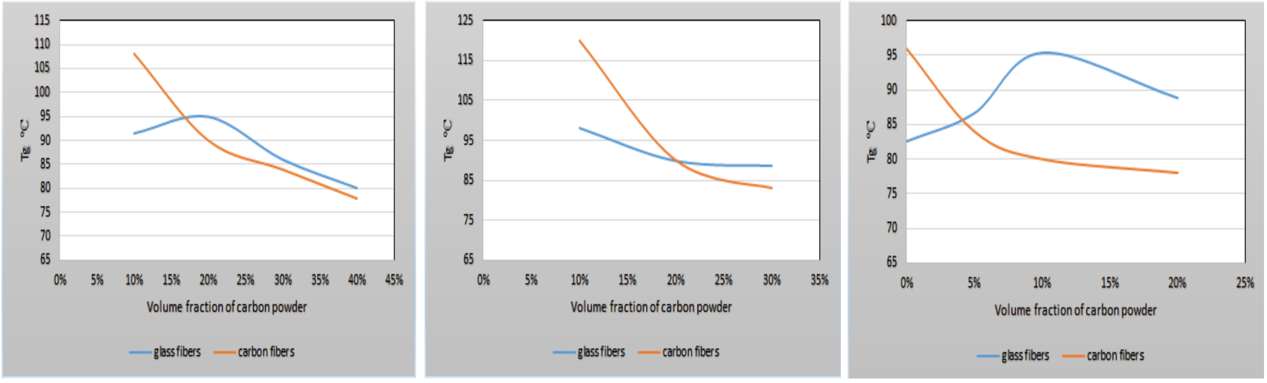
50% fibers 60% fibers 70% fibers

Figure 12. The effect of replacing fiber with powder on the thermal effusivity.



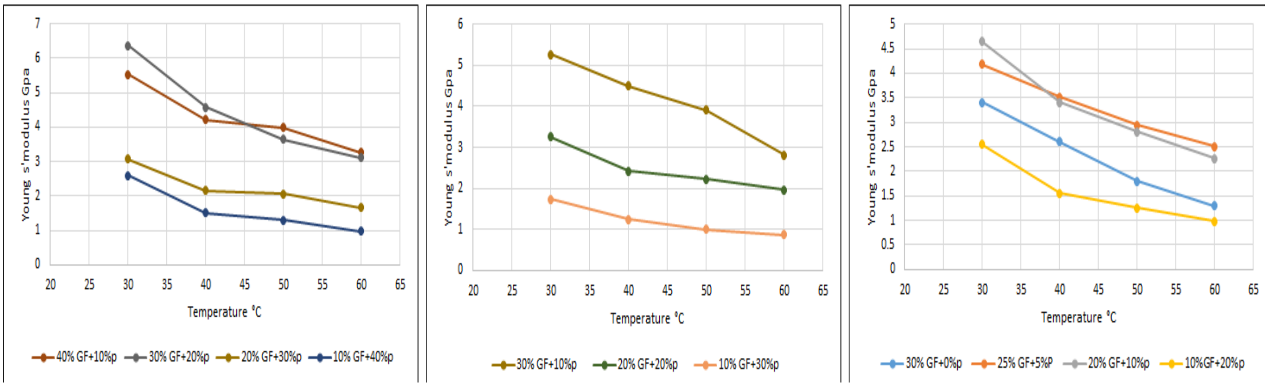
50% fibers 60% fibers 70% fibers

Figure 13. The effect of replacing fiber with powder on the thermal expansion.



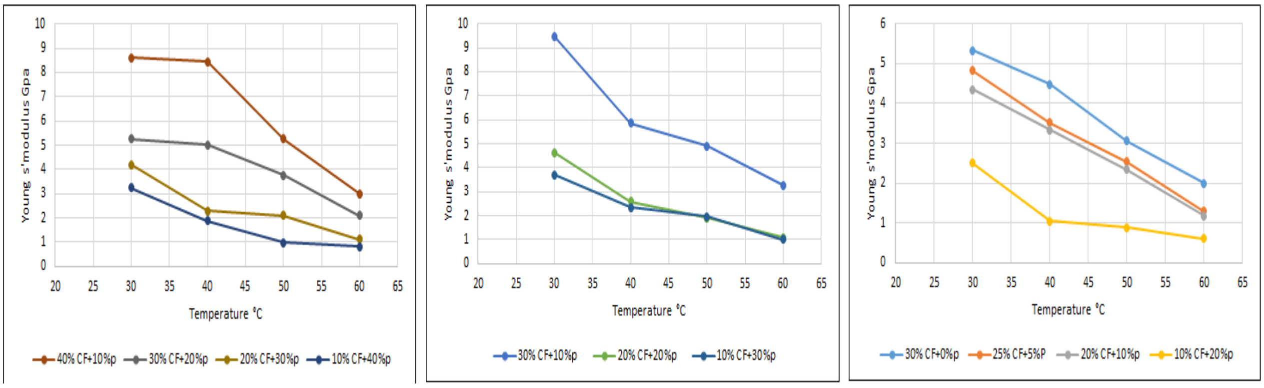
50% fibers | 60% fibers | 70% fibers

Figure 14. The effect of replacing fiber with powder on glass transition.



50% fibers | 60% fibers | 70% fibers

Figure 15. The effect of temperature on Young 's Modulus reinforcement with glass fiber.



50% fibers | 60% fibers | 70% fibers

Figure 16. The effect of temperature on Young 's Modulus reinforcement with carbon fiber.

4. Conclusion

The most important conclusions that have been reached by this study are,

1. The addition of carbon powder to the composite material composed of polyester resin with glass or carbon fibers improves the mechanical and thermal properties.
2. The addition of carbon powder has a small effect on the materials composed of carbon fibers in comparison with its effect on the materials composed of glass fibers.
3. Hyper composite materials contain of carbon fibers has highest mechanical properties when compared it with materials contain of glass fibers.
4. Hyper composite materials contain of glass fibers has highest thermal properties when compared it with materials contain of carbon fibers.
5. The best mechanical and thermal properties for the specimens composed of 50% polyester, 30% glass fibers and 20% carbon powder.

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