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Effect of Filler Type on some Physical and Mechanical Proparties of Carbon Fibers / Polyester Composites

Dr. Osama Sultan Muhammed
Materials Engineering Department, University of Technology/Baghdad
Dr. Abbas Khammas Hussein
Materials Engineering Department, University of Technology/Baghdad
Ruaa Haitham Abdel-Rahim
Materials Engineering Department, University of Technology/Baghdad
Email:LoLo_ru1989@yahoo.com

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ABSTRACT

In the present study, traditional and hybrid composites were prepared by Hand lay-up molding and investigated. The composites constituents were unsaturated polyester resin as the matrix, 3% and 6% volume fractions of carbon fibers as reinforcement and 3% of Al_2O_3, Al, Cement and local Gypsum (calcium sulfate anhydrate CaSO4) as filler particles. The investigated physical properties were density, porosity while the mechanical properties were tensile properties, bending modulus of elasticity. The experimental results showed that increased volume fraction of carbon fibers to (6%) led to increase in physical properties (density, porosity. As for the mechanical properties, carbon fiber composites and (3% carbon fibers/Al_2O_3)-contained hybrid composites gave the higher tensile and fracture strength, carbon fiber then gypsum composites gave the higher bending modulus.

Keywords: Tensile, Bending Modulus, Carbon Fibers, Hybrid Composites.

تأثير نوع الاضافه على بعض الخواص الفيزيائيه والميكانيكيه من الياف كاربون ومتراكبات البولي استر

الخلاصة

تم في هذا البحث تحضير مواد متراكبة تقليدية وهجينة بواسطة طريقة المقالبة اليدوية ودراستها. تم نحضيرالمواد المتراكبة مكونة على راتنج البولي استر الغير مشبع كماده اساس وبألياف كاربون بكسر حجمي 3%و6% وكذلك 3% دقائق تدعيم من اوكسيد الالمنيوم، الالمنيوم، السمنت وكبريتات الكالسيوم اللامائية. الخواص الفيزيائية التي تم فحصها كانت (الكثافة, المسامية) بينما الخواص الميكانيكيه كانت (الشد , معامل مرونة الانحناء. أظهرت النتائج التجريبية بأن زيادة الكسر الحجمي لألياف الكاربون الى ٦% ادت الى زيادة االخواص الفيزيائية (الكثافة، المسامية). بالنسبه للخواص الفيزيائية اظهرت النتائج ان

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

المتراكبات الهجينة الحاوية على الالومينا اعطت اعلى كثافة ، المتراكبات التقليدية من الجص اعطت اقل مسامية. بالنسبه للخواص الميكانيكية فأن متراكبات الياف كاربون والمتراكبات الهجينة الحاوية على (٣% الياف كاربون / الومينا) اعطت اعلى مقاومة شد وكسر، المتراكبات التقليدية ذات الياف كاربون والاخرى ذات الجص اعطت اعلى معامل انحناء.

INTRODUCTION

The development of composites containing more than one type of reinforcement (hybrid composites) is motivated by the ability to combine advantageous features of various reinforcement systems – improved performance as well as reduced weight and cost. Hybrid composites facilitate the design of material with specific property matched to an end use. It is critical to understand the mechanical properties of hybrid composites to optimize the design of new hybrid materials [1].

Generally Hybrid applies to advanced composites and refers to use of various combinations of fibers or particulate in either thermoset or thermoplastic matrices [2]. Fiber reinforced materials become increasingly important for constructions of all kinds of applications such as Airplane engine covers, Fire resistant decorative boards, body fillers, work-surfaces, helicopter rotor blades and pump impeller blades[3].

Cecen V. et. al., (2006) had studied about the interaction between carbon fiber and polyester matrix. The fabric composites were tested in three directions: at 0^{o}, 45^{o}, and 90^{o}. The most significant result of their investigation is the strong correlation between the changes in interlaminar shear strength values and fiber orientation angle, in the case of UD carbon fabric laminates. In addition, the lamina stacking sequence and laminate type have a significant effect on the recorded values of the interlaminar shear strengths [4].

Khanam P. N. et. al., (2010), had studied the variation of mechanical properties such as tensile and flexural properties of randomly oriented unsaturated polyester based sisal / carbon fiber reinforced hybrid composites. They showed an increase in tensile and flexural properties with increase in carbon fiber loading [5].

Falak A. O. et. al. , (2010), had studied the properties and behavior of particles on (glass, carbon, and Kevlar fiber) reinforced polyester composites. The effect of Al_2O_3 and SiC particles are investigated at different volume fraction (i.e. 0.2, 0.4, 0.6, 0.8, 1.0%). Comparative analysis showed that the impact resistance and hardness are increased with increasing the particles volume fraction especially (0.5%), and decreased for bending distortion especially in case of glass fiber/ polyester at (0.5%) volume fraction for both filler particles.

In the present study, carbon fiber reinforced polyester with different types of particles were prepared, tested and investigated[6].

EXPERIMENTAL WORK

Materials Used

The basic materials used in the preparation of research samples consisting of Carbon fibers from the Tenax company England, and unsaturated polyester resin as the matrix from the SIR Saudi Arabia company in the form of transparent viscous liquid at room temperature which is a thermally hardened polymers (Thermosets) with a density of (1.255 g / cm3). The used particles were; Aluminum from the company RIEDEL – DE

HAEN AG German origin with a particle size of 35 µm, Aluminum oxide with a particle size of 16 µm, particles of Cement with a particle size 16 µm, and Gypsum with particle size of 107 µm. Table (1) shows the components of the cement, which was analyzed at the general company of geological survey and mining, Baghdad, Iraq.

Table (1)The components of the cement %wt.

SiO_2	Fe_2O_3	Al_2O_3
20.21	3.05	4.98

Mould Preparation

All the required moulds for preparing the specimens were made from glass with dimensions of (250×250×5) mm. The inner face of the mould was covered with a layer of nylon (thermal paper) made from polyvinyl alcohol (PVA) so as to ensure no-adhesion of the resin with the mould.

Preparation of Composites

The composites samples were prepared from unsaturated polyester reinforced with carbon fiber of 3% and 6% volume fraction, and particles of various materials (Aluminum, Aluminum Oxide, Cement, local Gypsum) with a constant volume fraction of 3%. The method used in the preparation of the samples in this research is the (Hand lay-Up Molding) because it is simple to use and can make different shapes and sizes of composites. Figure (1) shows some of the specimens Prepared by hand lay-mobling.

 Unsaturated polyester+3%Al	 Unsaturated polyester +3%C.F+3%Al	 Unsaturated polyester +3%C.F+3%Al_2O_3
 Unsaturated polyester +3%C.F+3%Cement	 Unsaturated polyester +3%C.F+3% Gypsum	 Unsaturated polyester+6%C.F+3%Al
 Unsaturated polyester+6%CF+3% Al_2O_3	 Unsaturated polyester+3%CF	 Unsaturated polyester+6%CF

Figure (1) some of the specimens prepared by hand lay-up molding

PHYSICAL TESTS

Density Measurements

The role of mixture (ROM) formula is used to calculate the theoretical density of the composite. While true density test is performed according to (ASTM C 373) standard. The samples were cut into a diameter of 40 mm and a thickness of 5 mm the true density (ρ_t) is calculated from the method of immersion in water using the following relationship[7]. Figure١ shows the prepared specimens for this test.

$$\rho t= (Wd /Ws-Wn)*D \qquad \dots(1)$$

Where:

ρt: true density or bulk density (g/cm^3).
D: Density of distilled water (1 g/cm^3).
Wd: dry weight of sample (g).
Wn: weight of the sample, a commentator and submerged with water (g).
Ws: weight of the sample is saturated with water (g).

Figure (2) Prepared specimens.

Porosity

The porosity of composites is calculated for all specimens using the following formula [8].

$$\% P = [1- (\rho_{t} / \rho_{c})] * 100 \qquad \dots(2)$$

Where:

% P: porosity percent.
ρ_t: true density.
ρ_c: composite theoretical density.

MECHANICAL TEST

Tensile Test Measurement

The role of mixture (ROM) formula is used to calculate the tensile strength of the composites. While true tensile strength is performed according to ASTM D638 at room temperature with 20KN applied load and strain rate of 0.5 mm/min by using the machine type WDW-200E, Chinese made. Figure 3 shows the prepared specimens for tensile test.

Figure (3) Experimental specimens before& after test.

Bending Test

This test is performed according to ASTM D790 at room temperature. Samples were cut into the dimensions (191*13*4.8). Figure 4 shows the prepared specimens for bending test. Modulus of elasticity was calculated according to the following equation [9].

$$E = M\,g\,L^3/48\ \mathrm{I}\ \mathrm{S} \qquad \ldots (3)$$

Where:

M: mass inflicted on the sample (g).
g: the accelerate and value (9.81 m/sec^2).
L: the distance between bearing points (mm).
S: bending resulting from load inflicted (mm).
I: moment of inertia of the cross section of the sample (m^4). It is calculated from the following relationship [10].

$$\mathrm{I} = \mathrm{bd}^{\,3}/12 \qquad \ldots (4)$$

Where:

b: width sample (mm).
d: Thickness of the sample (mm).

Figure (4) Bending specimens.

RESULTS AND DISCUSSION

Density and Porosity

Table (3) shows the values of density and porosity for the prepared composites. It can be seen that the density of hybrid composites is higher than that of the traditional ones which is due to the addition of reinforcement that have higher densities than the matrix.

When comparing the values of true density with the values of theoretical density which are calculated by the role of mixture (ROM), it can be seen that all the true density values are lower than the theoretical ones. The lower values may be to the presence of defects (porosity and voids) resulted during the composites preparation [11]. Figures (7) to (12) show the true and theoretical densities for each type of composites. Figures (13) to (15) show the porosity percentage for each type of composites.

From the Table and Figure (7), it can be seen that the true density of (UP/ 6%C.F) is lower than that of (UP/ 3%C.F). While in Figure 8, the opposite effect is resulted which is true since the carbon fibers have higher density than polyester and increasing its content can increase the density according to the role of mixture. The reason for the decreased density of (UP/ 6%C.F) in Figure (7) is due to the increased porosity percentage as indicated in Figure (13) In Figure (7), the higher density was found to be for the gypsum then alumina composites. This is true since both have the higher individual densities when compared with the other reinforcements.

For hybrid composites with 3%C.F in Figures (9 and 10), the higher density was found to be for alumina then gypsum composites. For hybrid composites with 6%C.F in Figure (11), the higher densities was found to be for gypsum composite then cement, alumina and finally Aluminum which differs from the results of theoretical density in Figure 12 and the results of 3%C.F hybrid composites. The reason of that may relate with the preparation method itself. In that the preparation of composites with more than two materials is difficult and the increasing in volume fraction of any constituent can increase the difficulty and effect directly on the shrinkage of the matrix, and may create more voids-preferred sites.

The results of porosity are indicated in Figures (14 and 15) for hybrid composites. It is important to note that in spite of the lower grain size of cement, its lower individual density when compared to that of the other particle reinforcements and the right preparation method.

Table (3) Density and Porosity of the prepared composites.

Type of composite	**True density (g/cm^3)**	**Theoretical density (g/cm^3)**	**Porosity percent % P**
G1			
1-UP+3%C.F	1.248	1.271	1.859
2-UP+6%C.F	1.218	1.288	5.434
3-UP+3%Al	1.256	1.298	3.235
4- UP+3%Al_2O_3	1.277	1.339	4.630
5- UP+3%Cement	1.237	1.289	4.034
6- UP+3%Gypsum	1.283	1.306	1.761
G2			
1-UP+3%C.F+3%Al	1.280	1.315	2.661
2-UP+3%C.F+3%Al_2O_3	1.285	1.355	5.219
3-UP+3%C.F+3%Cement	1.113	1.306	14.777
4-UP+3%C.F+3%Gypsum	1.2٨	1.322	3.177
G3			
1-UP+6%C.F+3%Al	1.078	1.331	19.047
2-UP+6%C.F+3%Al_2O_3	1.274	1.372	7.142
3-UP+6%C.F+3%Cement	1.٢٨٧	1.322	2.647
4-UP+6%C.F+3%Gypsum	1.3	1.339	2.912

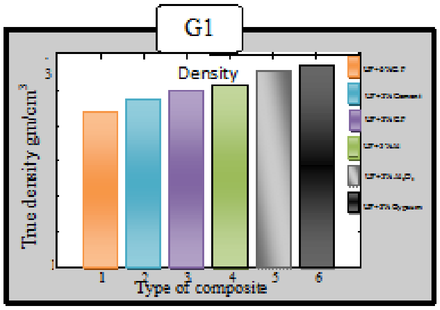


Figure5:True density of tradational composites

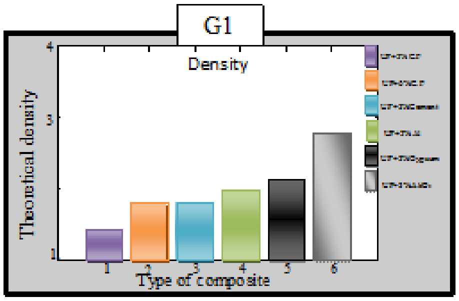


Figure 6: Theoretical density of tradational composites

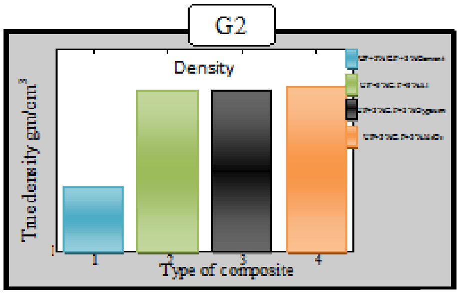


Figure7:True density of hybrid composites with 3%C.F.

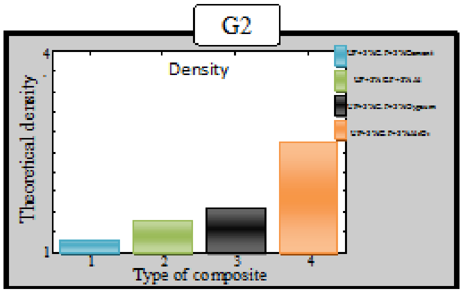


Figure 8: Theoretical density of hybrid composites with 3%C.F.

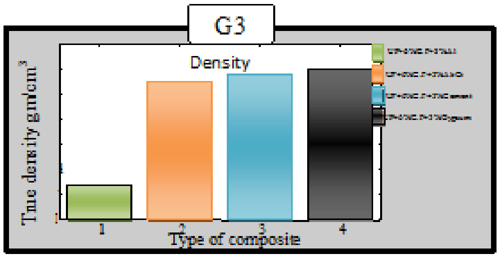


Figure9:True density of hybrid composites with 6%C.F.

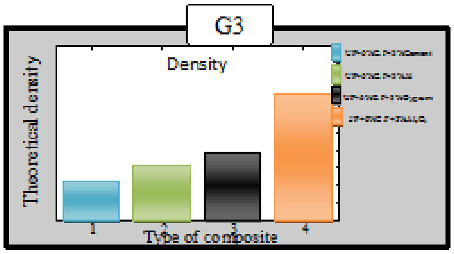


Figure 10: Theoretical density of hybrid composites with 6%C.F.

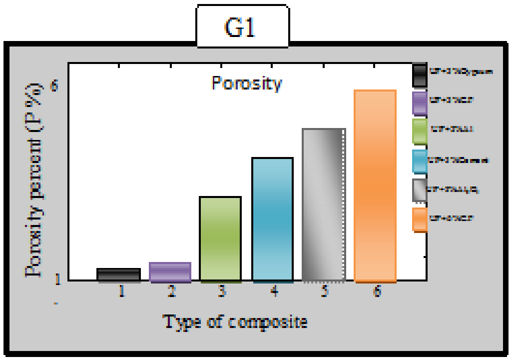


Figure 11: Porosity percent (P %) of tradational composites**.**

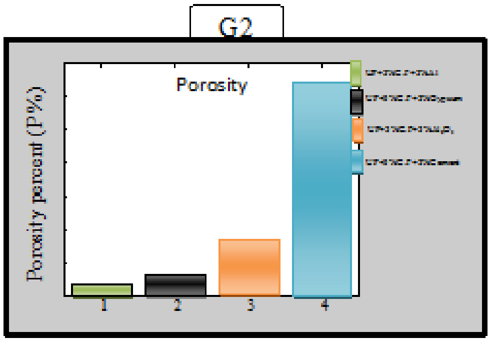


Figure 12: Porosity percent (P %) of hybrid composites with 3%C.F.

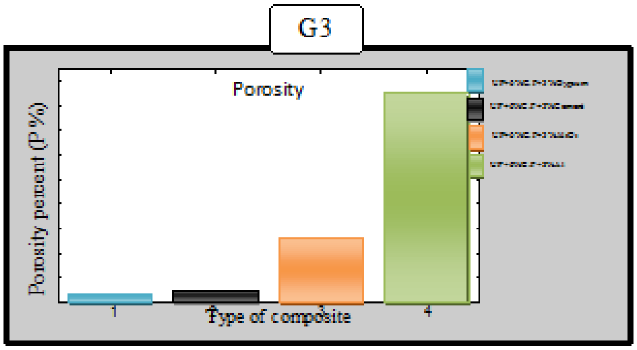


Figure 13: Porosity percent (P %) of hybrid composites with 6%C.F.

Tensile Strength

Table (4) shows the resulted values of ultimate tensile strength (UTS) and fracture strength for the composites. It can be seen that the actual UTS values is less than the theoretical ones for each group due to the presence of defects and crack initiation sites. The decrease in actual UTS values is also attributed to the effect of curing process during the composites preparation which can cause thermal residual stresses in the composites because of the difference in the coefficient of thermal expansion (CTE) between the composite constituents.

The general trend of stress-strain curves for (UP) reinforced with [G_1, G_2, G_3] groups is non-ductile without necking, and the sudden failure occurs from ultimate tensile stress (UTS) to failure stress as shown in Figures (16) to (18). It can be seen that fracture occurs shortly after reaching UTS. This is an evidence of the non-ductile behavior of the composites.

The effect of each type and volume fraction of reinforcements is illustrated in the Table and Figures (19) to (27). In general, it shows that the hybrid composites had gave the higher values of UTS and fracture strength. This is attributed to their higher hardness. Fibers are the main load carrying agents in composites and as the number of load carrying elements increases in a material, its strength increases [12]. Individually, the carbon fiber composites had gave the higher results due to the fibers that can bear more loads when compared to the particles as shown for the (UP/6% C.F). Also the tensile strength of the composites increases with increasing the fiber volume fraction.

It is observed that the tensile strength of the composites which contain Aluminum is higher than the others which can is due to the ductile nature of Aluminum that can give little more resistance before reaching the fracture. On the other hand, the high UTS of Alumina composites in Figure (20) may be a direct result of the good bonding among the composites constituents with the small grain size of Alumina relative to other additives.

Weak cross-linking can cause a kind of friction between the reinforcements and base material, which leads to sliding between the particles [13]. This can be the reason for the lower UTS values in other composites.

The decrease in strength with the addition of particles may be due to non-wetting behavior of the filler particles with the matrix and may be due to the non-uniform distribution of the particles. The efficiency of load transfer between the matrix and reinforcements depends directly on the bonding which in turn depends on wetting of surfaces. The non-uniform distribution of particles may reduce wetting and bonding, and as a result of excessive particles that were not well dispersed in the polymer, stress concentrations and defects will be created in the matrix, and thus decreases the tensile strength [14]. In general, the clustering or entanglement of particles and/or fibers in some areas and the irregularities may create resin poor areas and so weaken the forces of adhesion as well as creating many of defects within the composites and other defects formed within the fiber layer itself and that this will lead to the generation of many areas to focus the stresses which accelerate the process of failure of the sample and making the material behave as a brittle [15].

Table (4) Tensile strength for (UP) reinforced with groups [G_1, G_2, G_3].

Type of composite	σ_{UTS} (Mpa)	Theoretical tensile strength σ_c (Mpa) (14,15)	$\sigma_{fracture}$ (Mpa)
1-Unsaturated polyester(UP)	26.557	26.557	25.372
G1			
2-UP+3%C.F	39.652	100.760	36.790
3-UP+6%C.F	63.250	174.963	59.176
4-UP+3%Al	38.846	28.459	35.984
5- UP+3%Al_2O_3	32.363	34.010	32.363
6- UP+3%Cement	30.533	25.835	30.533
7- UP+3%Gypsum	31.743		31.743
G2			
1-UP+3%C.F+3%Al	51.886	102.663	51.886
1-UP+3%C.F+3%Al_2O_3	54.080	108.213	54.080
3-UP+3%C.F+3%Cement	38.246	100.038	38.246
4-UP+3%C.F+3%Gypsum	39.871		39.872
G3			
1-UP+٦%C.F+3%Al	52.917	176.866	49.069
2-UP+٦%C.F+3%Al_2O_3	44.261	176.866	41.262
3-UP+٦%C.F+3%Cement	40.177	174.241	37.057
4-UP+٦%C.F+3%Gypsum	51.979		47.565

Bending test

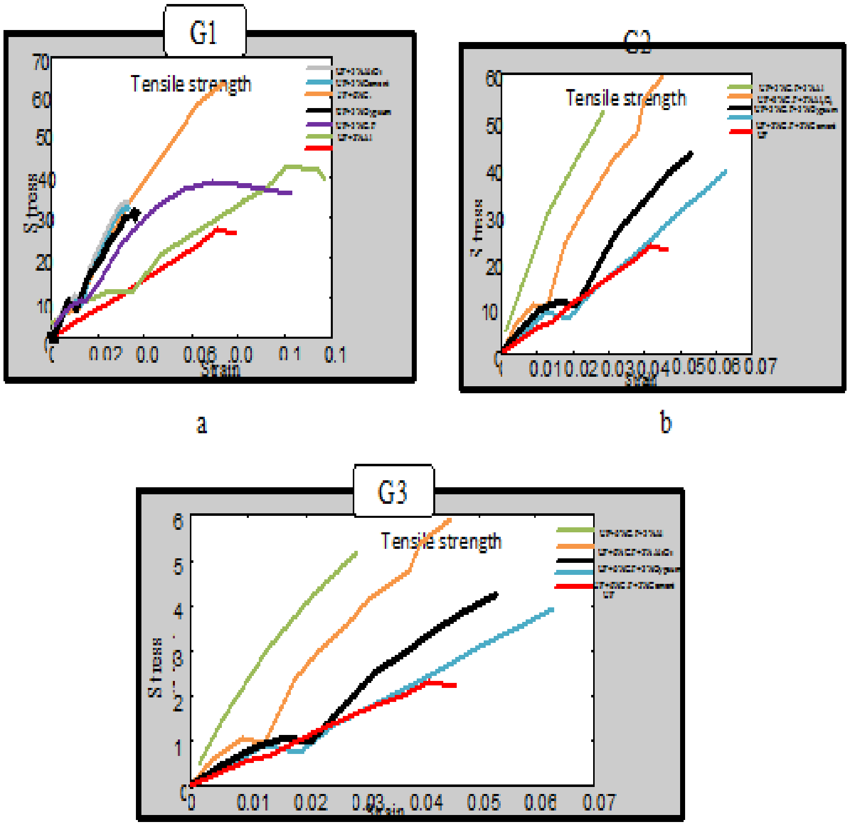
The results of Elastic modulus ($E_{bend.}$) for the UP reinforced with (G_1, G_2, G3) groups are illustrated in Table (5) and Figures 28to 30.

It is clear that the bending elastic modulus of UP is lower than that of composites. The reason is that UP has lower hardness than composites. Increasing the carbon fibers volume fraction had led to increasing the elastic modulus as can be seen in the results of (UP/3%CF) and (UP/6%CF). This is due to the decrease in the deformation (δ) by increasing surface contact area between reinforcement and matrix [16]. Also the high modulus of elasticity of carbon fibers itself, make it to give their composites higher results than the other once.

From observing of the Figures, it can be seen that the results of (G_1) is higher than that of other groups. Although more reinforcements in the hybrid composites had gave it higher hardness, it also gave it a little more brittleness and defects. Also, the added particles may reduce the coherence of interface area and by which increasing the air glades and defects, which may be the reason for lowering its values of bending elastic modulus.

Table (5): Modulus of elasticity for (UP) reinforced with groups [G_1, G_2, G3].

Type of composite	**Modulus Of elasticity(E) (Mpa)**
1-Unsaturated polyester(UP)	4003.38
G1	
2-UP+3%C.F	5026.42
3-UP+6%C.F	5450.12
4-UP+3%Al	9424.63
5- UP+3%Al_2O_3	7539.7
6- UP+3%Cement	5450.39
7- UP+3%Gypsum	9424.6
G2	
1-UP+3%C.F+3%Al	6031.76
2-UP+3%C.F+3%Al_2O_3	4224.48
3-UP+3%C.F+3%Cement	5961.6
4-UP+3%C.F+3%Gypsum	8535.5
G3	
1-UP+6%C.F+3%Al	7180.6
2-UP+6%C.F+3%Al_2O_3	4663.7
3-UP+6%C.F+3%Cement	4308.4
4-UP+6%C.F+3%Gypsum	6959.7

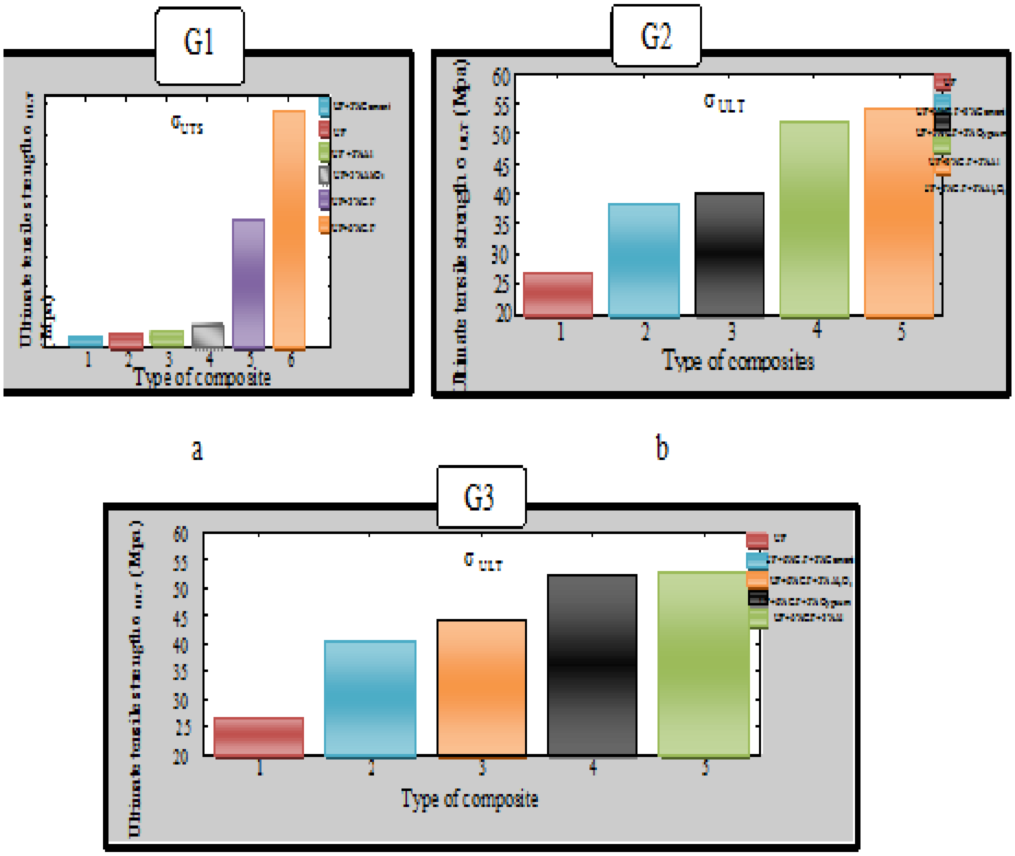


a

b

C

Figure 14: Stress-Strain curve. a -Stress-Strain of tradational composites.b - Stress-Strain of hybrid composites with 3%C.F.c - Stress-Strain of hybrid composites with 6%C.F.

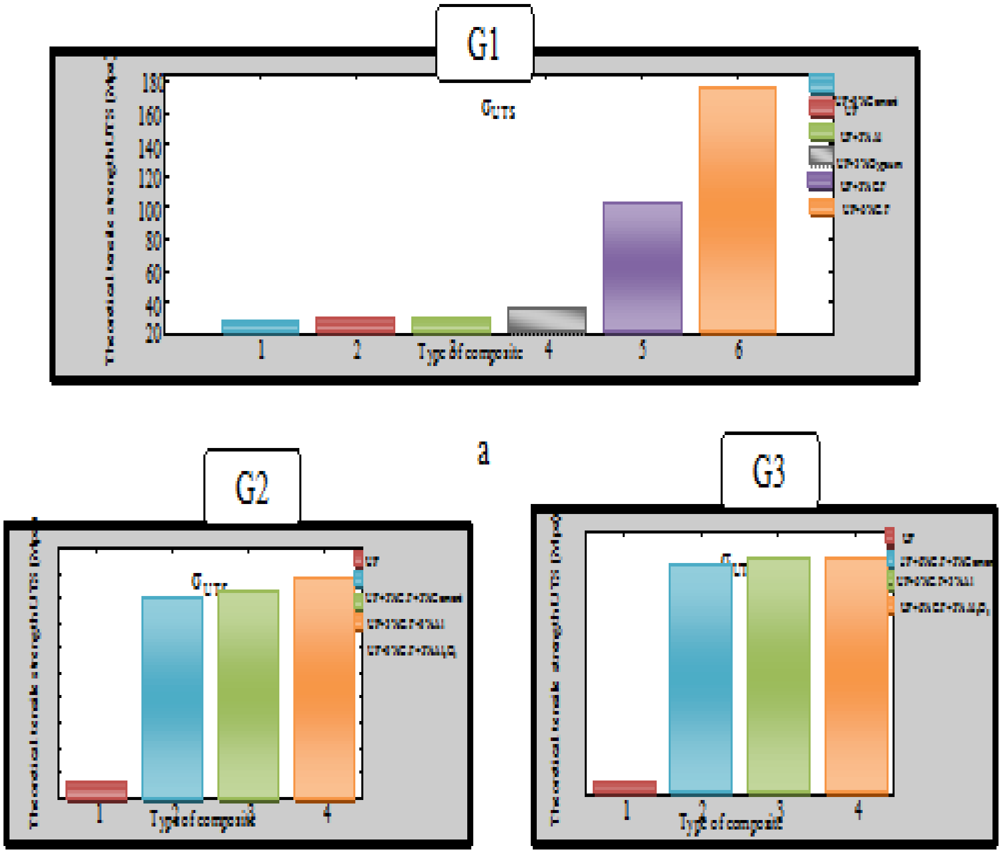


a

b

c

Figure 15: Ultimate tensile strength of composites.a - Ultimate tensile strength of radational composites.b - Ultimate tensile strength of hybrid composites with3%C.F.c - Ultimate tensile strength of hybrid composites with6%C.F



a

b

c

Figure16: Theoritical tensile strength of composites. a - Theoritical tensile strength of tradational composites.b - Theoritical tensile strength of hybrid composites with 3%C.F.

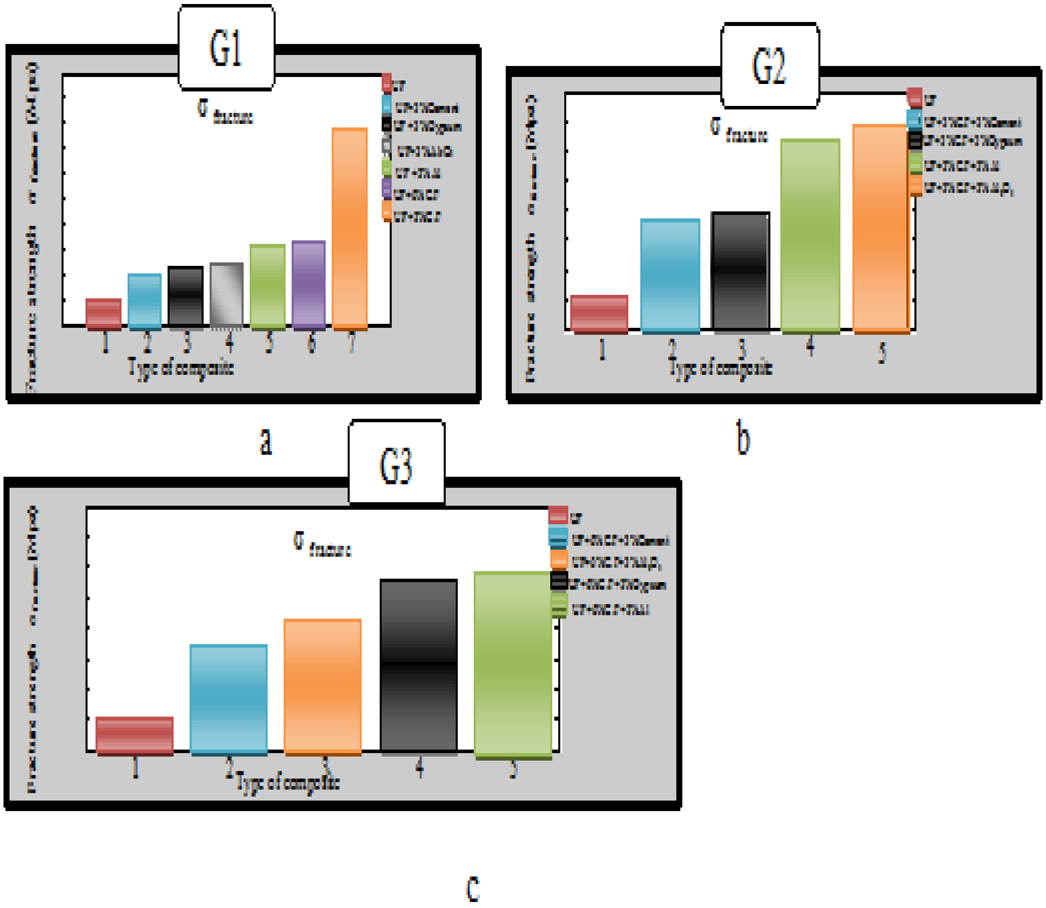
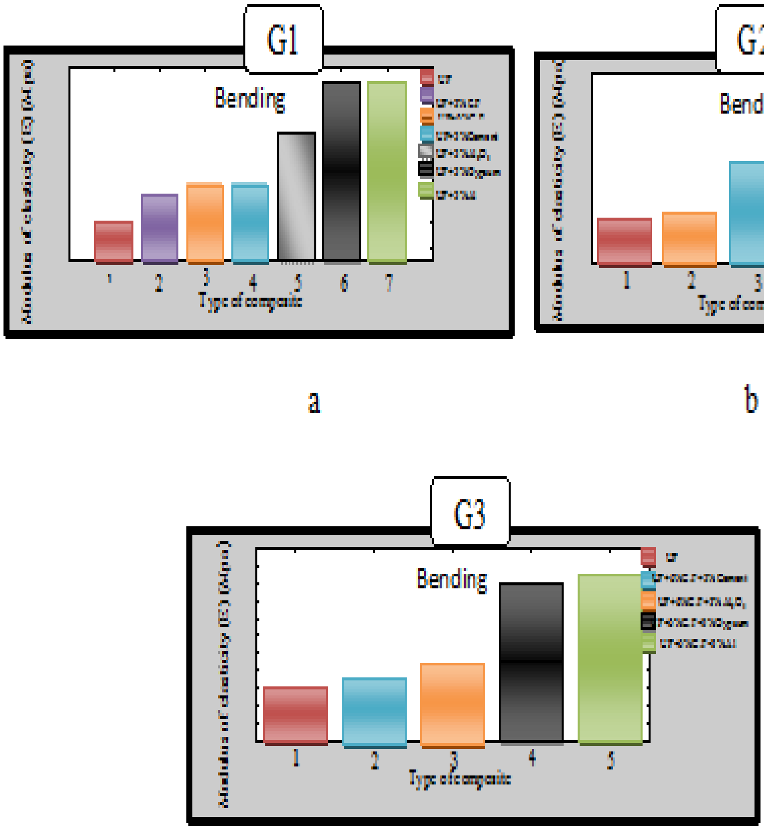


Figure17: Fracture strength of composites. a -Fracture strength of tradational composites. b -Fracture strength of hybrid composites with 3%C.F.c - Fracture strength of hybrid composites with 6%C.F.



a

b

c

Figure18: Modulus of elasticity of composites.a - Modulus of elasticity of tradational composites. b -Modulus of elasticity of hybrid composites with 3%C.F.c - Modulus of elasticity of hybrid composites with 6%C.F.

CONCLUSIONS

1- Non –reinforced unsaturated polyester (UP) has lower physical & mechanical properties than traditional composites & hybrid composites.

2- The values of true density are lower than that of the theoretical ones. Hybrid composite with 6%CF have the higher density when compared with other composites. Hybrid composite with (UP/6%CF/3% Gypsum) has the maximum density of (1.3) (gm/cm^3) when compared with other composites.

3- The porosity of traditional composites is lower than that of hybrid composites. The increased volume fraction of carbon fibers can make more preferred sites for porosity to be created. Traditional composite (with UP/ 3% Gypsum) has the minimum porosity of (1.761) P% when compared with other composites.

4- Traditional composites with carbon fibers have higher tensile, bending modulus than other composites. Those are followed by hybrid composites then particle composites in the sequence of the higher mentioned properties. Traditional composite (with UP/6%CF) has the maximum tensile strength , the maximum bending modulus of (9424.63) MPa than with other composites .

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