# Analyzing Mechanical Properties of Silica Gel Filled with Carbon Fiber into Polymeric Composite

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## Abstract

In this study, the effect of (1%, 2%, 3%, 4% weight fraction) waste silica gel reinforced with (3% weight fraction) carbon fiber into unsaturated polyester resin was investigated on the tensile properties, impact strength and shore D hardness. These samples of polymeric composite materials were manufactured by (Hand-lay-up) method. The average particle size of the silica gel was (5.3 to 136.4 µm). The mechanical properties were analyzed using SPSS one way analysis of variance to determine which weight fraction has more influence on mechanical properties where statistical significance was set at $P \leq 0.05$. Results showed that the highest mean values (164 ± 4.000 MPa), (7.367 ± .2517GPa) and (83.600 ± .2590) for tensile strength, elasticity modulus and hardness shore D respectively were recorded in sample (UP+3% C.F+4%Silica gel), while the highest mean values of elongation percentage (3.200 ± .2100), (2.700 ± .2100 ),(2.233 ± .1528) were recorded in samples (UP, UP+3% C.F, UP+3% C.F+1% silica gel) respectively, also highest mean values (10.9667±.07638) of impact strength was recorded in sample (UP+3% C.F+3% silica gel). The results of SPSS show that when (P) values less than (0.05) a significant effect of the filler material on the mechanical properties will be.

**Key Word**: Polymer resin, Carbon fiber, Silica gel, Mechanical properties, Statistical SPSS analyzing

## 1. Introduction

The composite materials consist of two or more materials that differ in mechanical, physical and chemical properties detach by a distinct interface [1]. The composite materials are classified based on matrix phase to a ceramic matrix composite, polymer matrix composites and metal matrix composites, polymer matrix material is widely used in various applications, industrial and classified into thermosetting, thermoplastic and elastomer polymer [2],[3].

Unsaturated polyester resin is widely used in many industries because it has many properties, the most important of which is the cheap material, gives structures high strength and at the same time lightweight, ease of handling with reinforcing materials during the casting process, long life compared with stone, ceramics, and metal [3],[4].

Some researchers have studied the effect of different fillings on some mechanical and physical properties of composite materials reinforced with fibers. Joao Marciano, et. al [5]. have studied the effect of (30%, 40%, 50% weight fraction) waste kraft paper residue on the tensile test and flexural test of polymer composites. From the results tensile strength, modulus of elasticity and flexural modulus increase with the increasing weight fraction of the kraft paper residue, but decreases the flexural strength values with the increasing weight fraction of the kraft paper residue. A. Athijayamani, et. al [6]. have investigated the effect of 10%, 15%, 20%, 25 %, 30%, 35%, 40%, 45%, 50%, 55% banana fiber / chopped agave sisalana variegata fiber hybrid content on the tensile test, flexural test and impact properties. The results showed that the sample (Vinyl Ester + 40% hybrid banana fiber / chopped agave sisalana variegataas) has the best mechanical properties when compared with the other weight fractions. Aseel. B., et. al [7]. study some mechanical and physical properties of epoxy resin reinforced with 6% glass fiber and 3%, 6% v.f rice husk ash, carrot fiber, and sawdust. Results show the samples (EP. +6% G.F+6% R.H, C.F, S.D) have values higher flexural strength, shear stress, hardness shore D, density and water absorption. Ruaa H., et. al [8]. have considered the effect of (4%, 8%, 12%, 16% wt.) eggshell waste with the epoxy resin matrix on hardness shore D, tensile strength, flexural strength and water absorption of polymer composites. From the results tensile strength, flexural strength, and hardness shore D increase with an added (16% wt. eggshell), but decreases the water absorption values with an added (16% wt. eggshell). The research focuses on taking advantage of the use of available waste in composites engineering industries, also study the effect wastes silica gel on the tensile test, impact strength and hardness shore D reinforced with carbon fiber in unsaturated polyester resin.

## 2. Materials

### 2.1 Unsaturated Polyester Resin

Table 1 presents some mechanical and physical properties of the unsaturated polyester resin is equipped by a United Arab Emirates Company.

**Table 1 Mechanical and physical properties of unsaturated polyester resin**

| Properties | Values |
|---|---|
| Young modulus | > 2.06 GPa |
| Tensile strength | 65 MPa |
| Percentage elongation | ≥2.9 % |
| Flexural strength | 182-195 MPa |
| Density | 1.2 gm/cm$^3$ |

### 2.2 Carbon Fiber

Table 2 shows mechanical and physical properties of the woven carbon fiber used in this research provided by "Tenax Company, England made".

**Table 2 Properties of carbon fiber according to Tenax Company**

| Properties | Values |
|---|---|
| Tensile modulus | 240 GPa |
| Tensile strength | 3600 MPa |
| Elongation | ≥1.9% |
| Density | gm/cm3 |

### 2.3 Silica Gel

he silica gel used in this research as filler materials with a thermoset polymer resin. Table 3 shows the characteristics of the silica gel balls provided by the company. Figure 1 shows the shape of the silica gel before and after grinding for 1 hour using a laboratory mill. Figure 2 shows the gradation size of silica gel particles where silica gel powder was at D10 (5.318μm), D50 (60.98 μm) and the D90 (136.4 μm). X-ray

Diffraction of silica gel powder shown in Figure 3, showing sharp peaks of the diffraction angle (20.9, 21.9, 26.6, 31.4, 36.0) indicating crystalline silica. These values correspond to the crystalline distances between crystalline levels and their values (4.06, 3.35, 2.85, 2.49) as calculated from the (Bragg's law) according to the values of the International Center for Diffraction Data. The peaks showed X-ray diffraction with two types of tridymite thus the silica gel powder appears in crystalline formations together. The chemical composition of silica gel particles by Examination of Energy - Dispersive X-Ray Spectroscopy as shown in Figure 4.

**Table 3 Properties of silica gel particles**

| Properties | Values |
|---|---|
| Density | 0.7 gm/cm3 |
| Molecular formula | SiO2 |
| Melting point | 3110 ° F |
| Boiling point | 4046 ° F |
| Appearance | Transparent beads |
| Odor | Odorless |

a- Silica gel shaped balls

b– Mill used to grind the silica gel

c-Silica gel powder after milling for 1

**Figure 1 Shape silica gel particles before and after grinding**

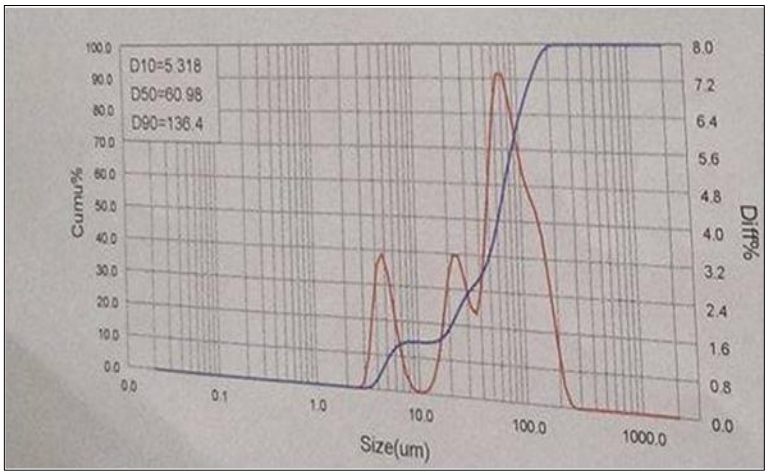


**Figure 2 Gradation particle size of silica gel powder after milling**

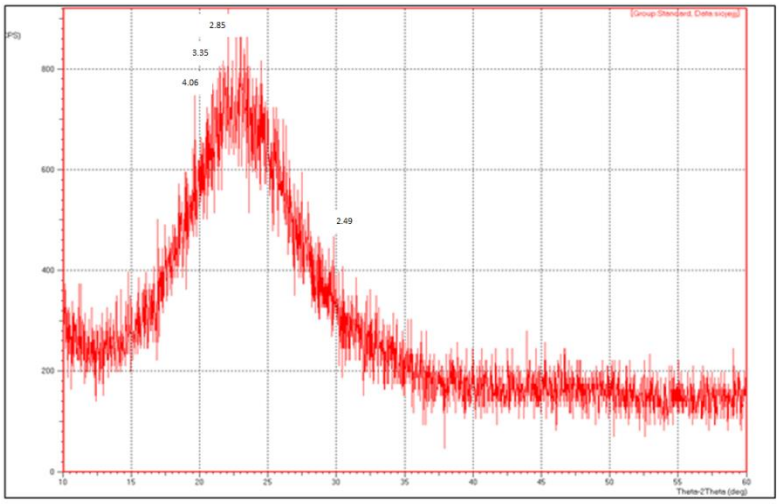


**Figure 3 X-Ray Diffraction of silica gel powder after milling**

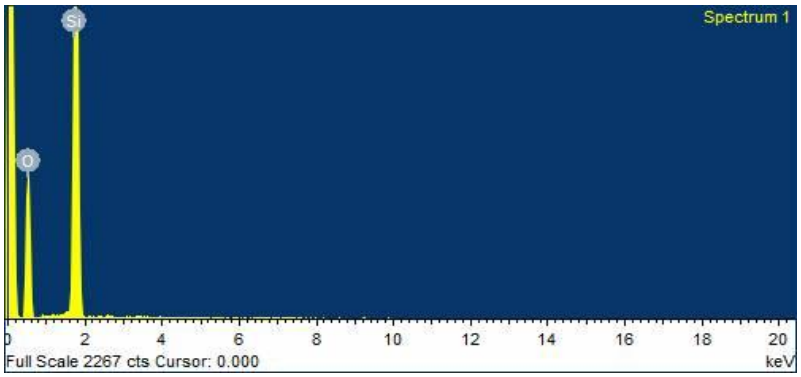


**Figure 4 Energy Dispersive X- Ray Spectroscopy of silica gel powder after milling**

## 3. Manufacturing of Polymeric Composite

Polymeric composite material samples were prepared in this study using hand-lay-up technique and are the oldest method of manufacturing composites. The materials used are 3% weight fraction carbon fiber with directional $90^{\circ}$ as reinforcement with different (1%, 2%, 3 %, 4%) weight fractions of silica gel powder into unsaturated polyester resin. For the manufacture of these polymeric composites must be prepared molds with dimensions (200mm×200mm×5mm). At the beginning poured the sample without any addition, through mixture unsaturated polyester resin with the hardener, after that pour the sample made of unsaturated polyester resin with carbon fiber, and then pour the different weight fraction of the silica gel powder it into the molds without any bubbles and waiting for 24 hours at room temperature. Samples are extracted from molds and putting in the oven at 50 °C for 2 hours to remove the remaining stress in these samples [9],[10]. The composition of samples is shown in Table 4.

**Table 4 Composition of samples composite materials**

| Samples | Composition |
|---|---|
| E0 | Pure unsaturated polyester |
| E1 | UP+ 3% C.F |
| E2 | UP+ 3% C.F+1% Silica gel |
| E3 | UP+ 3% C.F+2% Silica gel |
| E4 | UP+ 3% C.F+3% Silica gel |
| E5 | UP+ 3% C.F+4% Silica gel |

## 4. Mechanical Characterizations Test

### 4.1 Tensile Test

The tensile tests were performed according to ASTM D638-03 standard for samples with dimensions (5 mm thickness, 20 mm width, 150mm length) as shown in Figure 5 [11], [12].

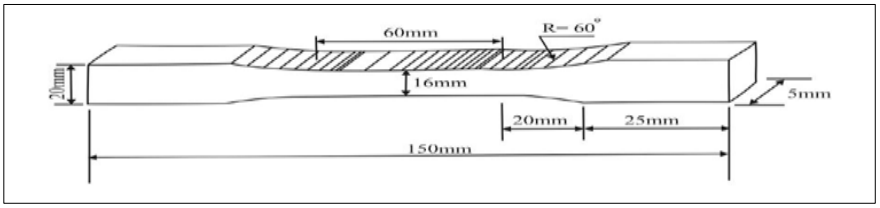


**Figure 5 tensile test standard**

### 4.2 Impact Test:

The impact tests were performed according to ASTM ISO-180 standard for samples with dimensions (4 mm thickness, 10 mm width, 80mm length) as shown in Figure 6 [13].

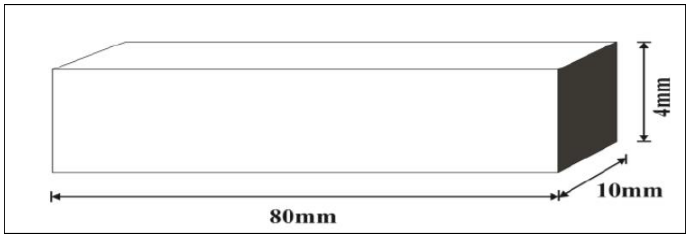


**Figure 6 impact test standard**

### 4.3 Hardness Shore D

The hardness shore D were performed according to ASTM D 2240 standard for samples with dimensions (5 mm thickness, 50 mm diameters) as shown in Figure 7 [14].

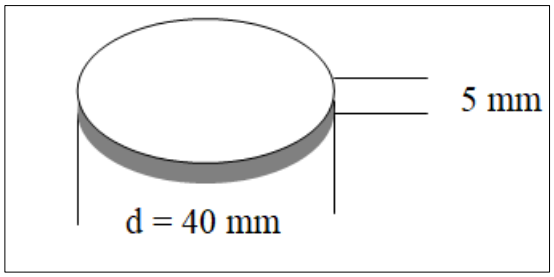


**Figure 7 hardness shore D**

## 5. Statistical analyses

The data were statistically dissolved using a one-way analysis of variance (ANOVA) followed by Tukey method. The determined values of results were performed with statistical analyses SPSS (statistics version 20). The events of the tests were estimated significant when P≤ 0.05 and also utilized to distinguish the variances among groups [15].

## 6. Results and Discussion

### 6.1 Tensile Strength

Table 5 shows the mean and std. deviation values tensile strength of samples polymeric composites and P derived from the Tukey test statistically analyzed by used (SPSS) software. Based on these results of the Table, it can be observed that the samples reinforced with 3% wt. carbon fiber and adding (1%, 2%, 3%, and 4%) weight fractions silica gel powder into unsaturated polyester resin are given better values of tensile strength (99 ± 4.033, 119 ± 4.509, 136 ± 3.606, 151 ± 3.000, 164 ± 4.000MPa) respectively than samples (neat and carbon fiber only). Table 6 illustrates one way ANOVA method among all samples where P value (0.001) was less than 0.05, this indicates that the weight fraction (1%, 2%, 3%, 4% silica gel with 3% carbon fiber in polyester resin) has a greater effect on tensile strength. Figure 8 shows that the increase in the weight fraction of silica gel powder, lead to an increasing value of tensile strength. The reason for increasing tensile strength with the addition of silica gel powder is that these powders with carbon fiber in unsaturated polyester resin provide the possibility of transferring the load from the resin matrix material to the reinforcement materials better than the sample without any filler, these results agree with [16], [17].

**Table 5 Tensile strength of the all samples with P –value derived from Tukey test**

| Tensile Strength (MPa) | | | |
|---|---|---|---|
| Samples | Mean | Std. Deviation | P |
| E0 | 63 | 1.528 | 0.132 |
| E1 | 99 | 4.033 | 0.04 |
| E2 | 119 | 4.509 | 0.03 |
| E3 | 136 | 3.606 | 0.02 |
| E4 | 151 | 3.000 | 0.007 |
| E5 | 164 | 4.000 | 0.001 |

**Values of P<0.05 indicate that difference between all samples modified sample is significant with the probability of 95%**

**Table 6 One Way ANOVA for results tensile strength**

| Samples | Sum of Squares | df | Mean Square | F | P |
|---|---|---|---|---|---|
| Between Groups | 20239.611 | 5 | 4047.922 | 282.413 | 0.001 |
| Within Groups | 172.000 | 12 | 14.333 | | |
| Total | 20411.611 | 17 | | | |

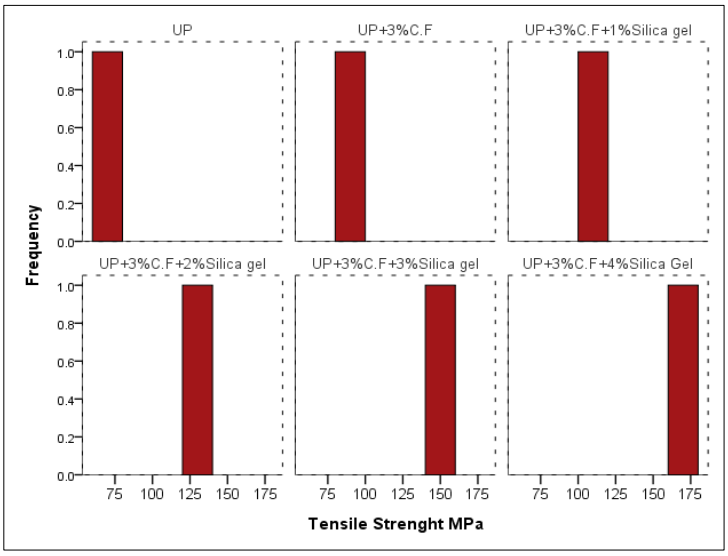


**Figure 8 Ultimate tensile strength values of all samples**

## 6. 2 Modulus of Elasticity

Table 7 shows the mean, std. Deviation and the P value derived from the Tukey test for the modulus elasticity values, it can be seen that the modulus of elasticity for polymeric composite material enhances significantly with the addition of 4% weight fraction silica gel powder, where the modulus of elasticity (GPa) values of samples (E2, E3, E4, E5) was (4.300 ±.2000), (5.267 ± .3512), (6.300 ± .3035), (7.367 ± .2517) respectively higher than sample pure unsaturated polyester and unsaturated polyester with 3% carbon fiber. Table 8 shown one way ANOVA to determine significant differences between all samples, it can be noticed that the value P is lesser than 0.05 (0.03< 0.05) this means that the carbon fiber and silica gel powder have a positive effect on the modulus of elasticity compared with unsaturated polyester resin matrix. The values of modulus of elasticity rise progressively with increased the weight fractions of silica gel powder as shown in Figure 9. This is due to two reasons, one of which is that the reinforcing materials contribute to increased roughness of the surface and this leads to increased mechanical properties and transfer of stress during polymeric composites, the second reason the spread of unsaturated polyester resin on the fiber surface and filler increases the bond between the reinforced the matrix materials [12],[18].

**Table 7 Modulus elasticity of the all samples with P –value derived from Tukey test**

| Modulus of Elasticity (GPa) | | | |
|---|---|---|---|
| Samples | Mean | Std. Deviation | P |
| E0 | 2.400 | .3000 | 0.083 |
| E1 | 3.400 | .4000 | 0.050 |
| E2 | 4.300 | .2000 | 0.040 |
| E3 | 5.267 | .3512 | 0.039 |
| E4 | 6.300 | .3035 | 0.032 |
| E5 | 7.367 | .2517 | 0.020 |

**Values of P<0.05 indicate that difference between all samples modified sample is significant with the probability of 95%**

**Table 8 One Way ANOVA for results modulus elasticity**

| Samples | Sum of Squares | df | Mean Square | F | P |
|---|---|---|---|---|---|
| Between Groups | 51.049 | 5 | 10.210 | 108.105 | 0.03 |
| Within Groups | 1.133 | 12 | .094 | | |
| Total | 52.183 | 17 | | | |

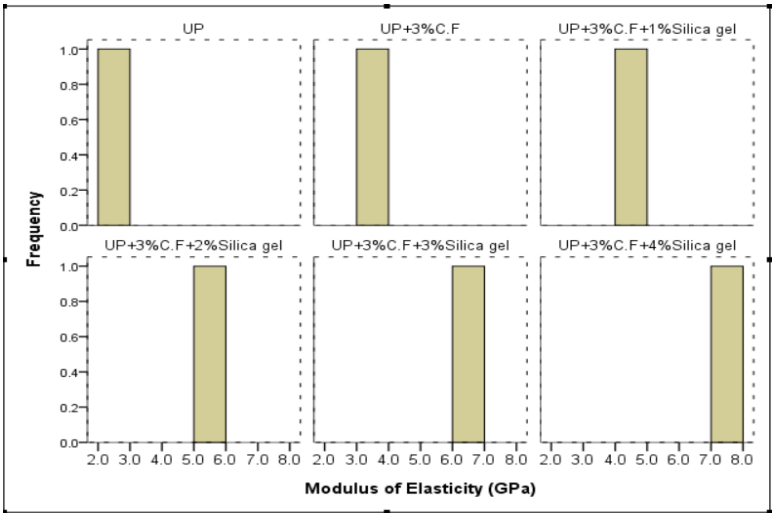


**Figure 9 Modulus of elasticity values of all samples**

## 6. 3 Elongation Percentage

Table 9 observed, the statistically analyzed by using (SPSS) software and followed by the Tukey test with the significance value of P 0.05 for the elongation percentage values. From this table can be noted that increase weight fraction silica gel powder decrease the elongation percentage because the addition of the particle-silica gel increases hardness surfaces of the polymeric composite materials and reduce from elongation percentage, where the mean values for samples (E2, E3, E4, E5) were (2.233 ± .1528 , 2.000 ± .1000 , 1.600 ± .2150 , 1.300 ± .2000) respectively less than samples (E0 and E1) (3.200 ± 0.2100 , 2.700 ± .2100 ) this means that the carbon fiber and silica gel powder into unsaturated polyester resin has a little effect on the elongation property . Table 10 illustrates the analyzed One Way ANOVA between all samples, form of these results the weight fraction (1%, 2%, 3%,4% with 3% carbon fiber) have little significance on the values of elongation percentage. Through Figure 10 we note that carbon fiber with silica gel powder into unsaturated polyester resin composites appear brittle behavior and this was expected since because the particles reinforced composites have low stiffness this agree with [19].

**Table 9 Elongation percentage of the all samples with P –value derived from Tukey test**

| Elongation Percentage % | | | |
|---|---|---|---|
| Samples | Mean | Std. Deviation | P |
| E0 | 3.200 | .2100 | 0.001 |
| E1 | 2.700 | .2100 | 0.002 |
| E2 | 2.233 | .1528 | 0.005 |
| E3 | 2.000 | .1000 | 0.046 |
| E4 | 1.600 | .2150 | 0.067 |
| E5 | 1.300 | .2000 | 0.107 |

**Values of P<0.05 indicate that difference between all samples modified sample is significant with the probability of 95%**

**Table 10 One Way ANOVA for results elongation percentage**

| Samples | Sum of Squares | df | Mean Square | F | P |
|---|---|---|---|---|---|
| Between Groups | 7.369 | 5 | 1.474 | 45.741 | 0.04 |
| Within Groups | .387 | 12 | .032 | | |
| Total | 7.756 | 17 | | | |

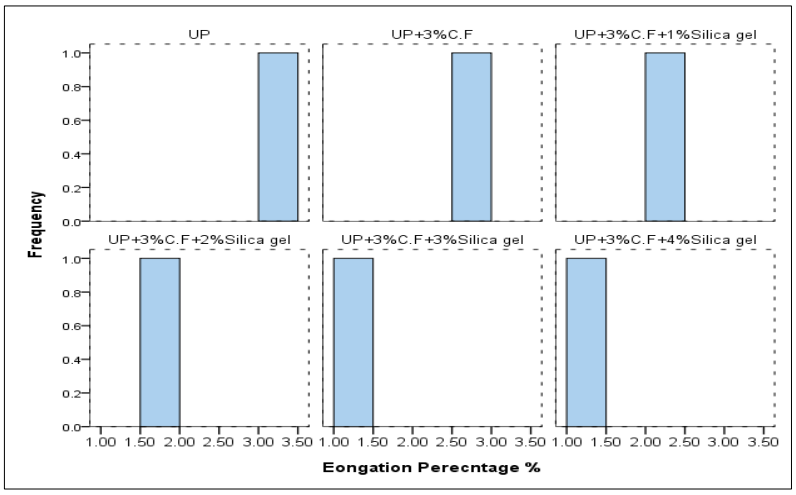


**Figure 10 Elongation percentage values of all samples**

## 6.4 Impact Strength

Table 11 shows test data the impact strength of unsaturated polyester resin reinforced with 3% carbon fiber and different weight fraction (1%, 2%, 3%, 4%) silica gel powder. From this Table the sample neat resin gives mean an impact strength of (9.8300 ± .03000 kJ/m2), while samples (E1, E2, E3) give mean an impact strength of (10.0033 ± .04726, 10.2667 ± .02517, 10.5300 ± .03310 kJ/m2) respectively, but the impact strength decreased significantly in the sample (E5) (10.7200±.02000 kJ/m2). Table 12 shown the test one way ANOVA to determine significant differences between all samples, from analyzing ANOVA can be noticed that it's the value $P< 0.05$ ($0.005 < 0.05$) this means that fillers materials (carbon fiber and silica gel powder) have a positive effect on the impact strength. Figure 11 illustrate that 3% carbon fiber with 1%, 2%, 3% silica gel powder improves the bonded between the matrix and reinforced materials that made these samples have the ability to absorb the impact force during test, while the impact strength decreases with 4% weight fraction silica gel powder because the small cracks spread easily and restrict the movement of polymer chains and this occurs as a result of non-homogeneity silica gel powder with resin matrix and fiber reinforcement [20] , [21].

**Table 11 Impact strength of the all samples with P –value derived from Tukey test**

| Impact Strength (K J /m$^2$) | | | |
|---|---|---|---|
| Samples | Mean | Std. Deviation | P |
| E0 | 9.8300 | .03000 | 0.056 |
| E1 | 10.0033 | .04726 | 0.007 |
| E2 | 10.2667 | .02517 | 0.005 |
| E3 | 10.5300 | .03310 | 0.003 |
| E4 | 10.9667 | .07638 | 0.001 |
| E5 | 10.7200 | .02000 | 0.002 |

Values of P<0.05 indicate that difference between all samples modified sample is significant with the probability of 95%

**Table 12** One Way ANOVA for results impact strength

| Samples | Sum of Squares | df | Mean Square | F | P |
|---|---|---|---|---|---|
| Between Groups | 2.818 | 5 | .564 | 103.220 | 0.005 |
| Within Groups | .022 | 12 | .002 | | |
| Total | 2.840 | 17 | | | |

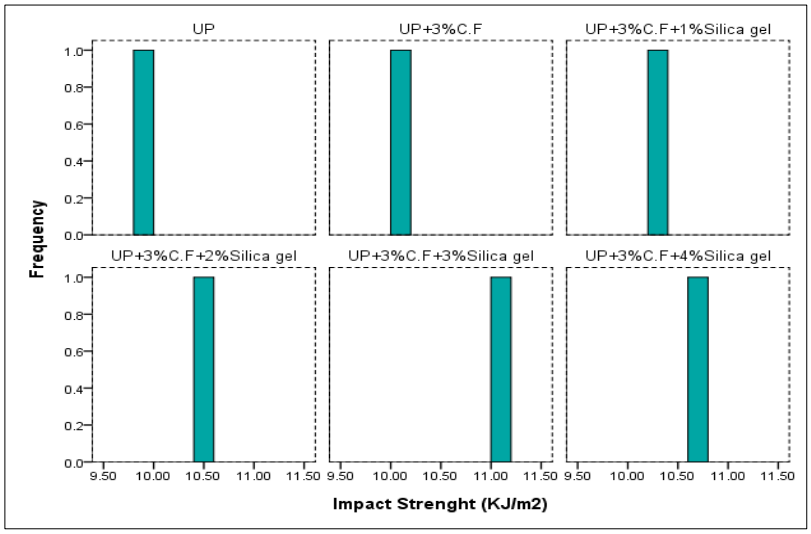


**Figure 11 Impact strength values of all samples**

## 6.5 Hardness Shore D

Table 13 shows the values hardness shore D for all samples which the statistically analyzed by using (SPSS) software and followed by Tukey test with the significance value of (P 0.05). From these results note increase values hardness shore D with increase weight fraction of fiber and particles, where the mean values increase from (75.567 ± .2014) for sample pure unsaturated polyester to (83.600 ± .2590) for sample (UP+3% carbon fiber + 4% silica gel). The analysis One Way ANOVA between all samples illustrated in the Table 14, noted that the values of (P=0.01) were less than (P<0.05), this means the reinforcement materials had a positive effect on the property of hardness shore D. Figure 12 demonstrates that 3% carbon fiber with 1%, 2%, 3%, 4% silica gel powder improves the bonded between the matrix and reinforced materials thus improved the values of hardness shore D. The reason for increasing is that the addition of fibers and particles giving a composite polymeric surface resistance to penetration with low flexibility low, this agrees with [22], [23].

**Table 13 Hardness shore D of the all samples with P –value derived from Tukey test**

| Hardness Shore D | | | |
|---|---|---|---|
| Samples | Mean | Std. Deviation | P |
| E0 | 75.567 | .2014 | 0.076 |
| E1 | 77.733 | .2243 | 0.016 |
| E2 | 80.600 | .2305 | 0.012 |
| E3 | 81.300 | .2405 | 0.040 |
| E4 | 82.700 | .2520 | 0.008 |
| E5 | 83.600 | .2590 | 0.003 |

Values of P<0.05 indicate that difference between all samples modified sample is significant with the probability of 95%

**Table 14 One Way ANOVA for results hardness shore D**

| Samples | Sum of Squares | df | Mean Square | F | P |
|---|---|---|---|---|---|
| Between Groups | 140.152 | 5 | 28.030 | 36.748 | 0.01 |
| Within Groups | 9.153 | 12 | .763 | | |
| Total | 149.305 | 17 | | | |

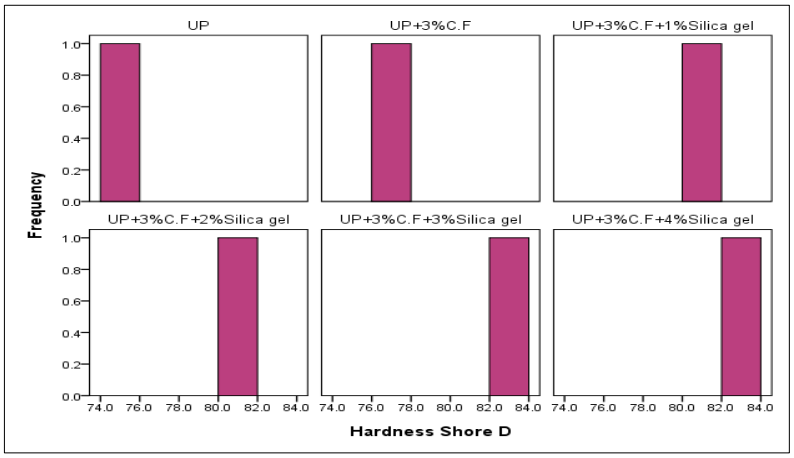


**Figure 12 Hardness shore D values of all samples**

## 7. Conclusions

The mechanical properties (tensile strength, elasticity modulus, percentage elongation, impact strength, and hardness shore D) were studied in the research of the unsaturated polyester composite reinforced with carbon fiber and silica gel powder. From the results of the tests obtained, the following conclusions, hand lay-up method was used to produce polymer matrix composites from unsaturated polyester /carbon fiber with silica gel powder. The sample (UP+3%C.F+4% Silica gel) has the highest values (164 ± 4.000MPa, 7.367 ± .2517 GPa, 83.600 ± .2590) for tensile strength, modulus of elasticity and hardness shore D respectively. The elongation percentage values decrease with the addition (1%, 2%, 3%, 4% weight fraction) silica gel powder, the highest values for elongation percentage were present in samples (UP, UP+3% C.F, UP+3% C.F+1%Silica gel) (3.200 ± .2100, 2.700 ± .2100 , 2.233 ± .1528) respectively. The sample (UP +3% C.F+3% Silica gel) has the highest values impact strength (10.9667 ± .07638 KJ/m2) compared with other samples. Statistical analysis, SPSS is used to select the best specimens from a set of alternatives, whenever the samples have values (P) less than 0.05 these sample best mechanical properties.

### Conflicts of Interest

The author declares that they have no conflicts of interest.

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# تحليل الخواص الميكانيكية لسيليكا المملوء مع ألياف الكربون في المتراكبات البوليمرية

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**الخلاصة**

في هذه الدراسة، تم دراسة تأثير (١ ٪ ، ٢ ٪ ، ٣ ٪ ، ٤ ٪ الكسور الوزني) السيليكا جل المقوى بألياف الكربون (٣ ٪ كسر وزني) في رانتج البولي استر غير المشبع على خصائص الشد ، مقاومة الصدمة وصلادة الشور (D). تم تصنيع هذه العينات من المواد المركبة البوليمرية بطريقة (الصب اليدوية). كان متوسط حجم الجسيمات من السيليكا جل (٥,٣ إلى ١٣٦,٤ ميكرون). تم تحليل الخواص الميكانيكية باستخدام SPSS تحليل التباين الاحادي لتحديد أي كسر وزني له تأثير أكبر على الخواص الميكانيكية حيث تم تعيين دلالة إحصائية عند P ≤ 0.05. أظهرت النتائج أن أعلى قيم متوسطه ( 164 ± 4.000 MPa)، (7.367 ± .2517GPa) و ( 83.600 ±.2590) لمقاومة الشد ، معامل المرونة وشور الصلادة D كانت مسجلة في العينة (البولي استر غير المشبع + ٣% ليف كاربون + ٤% سيليكا جل) ، في حين كانت أعلى قيم متوسطة لنسبة الاستطالة (٣,٢٠٠ ± ٢١٠٠.) ، (٢,٧٠٠ ± ٢١٠٠.) ، (٢,٢٣٣ ± ١٥٢٨.) كانت مسجلة في العينات (البولي استر غير المشبع ، البولي استر غير المشبع + ٣% ليف كاربون ، البولي استر غير المشبع + ٣% ليف الكاربون + ١% سيليكا جل) على التوالي، وأيضا كانت أعلى قيم متوسطة (١٠,٩٦٦٧ ± ٠٧٦٣٨.) لمقاومة الصدمة كانت مسجلة في العينة (البولي استر غير المشبع + ٣% ليف الكاربون + ٣% سيليكا جل). تظهر نتائج SPSS أنه عندما تكون قيم (P) أقل من (٠,٠٥) سيكون هناك تأثير كبير لمادة الحشو على الخواص الميكانيكية.

**الكلمات الدالة:**– رانتج البوليمر، ليف الكاربون، سيليكا جل، خواص ميكانيكية، تحليل احصائية (SPSS) .