# "Influence of Silica Nanoparticles on Physical and Mechanical Performance of Polyester Matrix Composites "

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ABSTRACT

The experimental procedure involved preparing composite materials using unsaturated polyester resin, cement, and silica nanoparticles. The materials were mixed in specific weight ratios and subjected to various tests. Field Emission Scanning Electron Microscope (FE-SEM) analysis showed that the presence and distribution of silica particles within the polymer matrix improved the mechanical properties of the composites.The impact strength of the composites increased after reinforcement with silica particles, indicating improved toughness and resistance to fracture.Hardness testing revealed that the addition of reinforcing materials increased the hardness of the composites compared to the polymer alone Thermal conductivity showed a slight increase with the addition of cement nanoparticles, but decreased when silica nanoparticles were added. Compressive strength and tensile strength tests demonstrated that the reinforced composites had higher strength values compared to the unreinforced polymer.Overall, the experimental results indicated that incorporating silica particles and cement nanoparticles into the unsaturated polyester resin enhanced the mechanical properties of the composites.

**Keywords:** Unsaturated polyester resin; Cement; silica nanoparticles; Mechanical propert

## 1.Introduction

Polyester matrix composites have gained significant attention in various industries due to their lightweight nature and excellent mechanical properties. These composites consist of a polyester resin matrix reinforced with different types of nanoparticles, such as silica nanoparticles, to enhance their performance characteristics. The incorporation of silica nanoparticles into the polyester matrix has shown promising results in improving the physical and mechanical properties of the composites.[1] .Silica nanoparticles possess unique properties such as high surface area, excellent mechanical strength, and good thermal stability. These properties make them suitable candidates for reinforcing polymer matrices. When silica nanoparticles are dispersed within the polyester matrix, they can significantly alter the composite's physical and mechanical behavior, leading to improved performance.[2] .

The influence of silica nanoparticles on the physical properties of polyester matrix composites is evident in several studies. For instance, Singh, Tej, et al. (2021) investigated the effect of different weight fractions of silica nanoparticles on the density, porosity, and water absorption of polyester matrix composites. They found that the addition of silica nanoparticles led to a reduction in the porosity and water absorption of the composites, resulting in improved dimensional stability and resistance to moisture.[3] In terms of mechanical properties, the incorporation of silica nanoparticles in polyester matrix composites has demonstrated enhanced tensile strength, flexural strength, and impact resistance. Research by Alameri, Ibrahim, and Meral Oltulu.. (2020) examined the influence of silica nanoparticles on the mechanical behavior of polyester matrix composites. They reported a significant improvement in tensile strength and flexural modulus with increasing nanoparticle content, attributing it to the efficient stress transfer between the matrix and nanoparticles.[4] Moreover, the addition of silica nanoparticles has also been found to enhance other mechanical properties such as hardness, scratch resistance, and fatigue resistance of polyester matrix composites. Studies conducted by Hao, Tian, et al. (2021) investigated the effect of silica nanoparticles on the hardness and scratch resistance of polyester-based nanocomposites. They observed that the incorporation of silica nanoparticles led to a substantial increase in hardness and scratch resistance, making the composites more suitable for demanding applications.[5]

The improvements in the physical and mechanical properties of polyester matrix composites due to the incorporation of silica nanoparticles can be attributed to various mechanisms, including increased interfacial adhesion, dispersion of nanoparticles, and the formation of a reinforcing network within the matrix.[6]

## 2.EXPERIMENTAL PROCEDURE

### 2.1 Material

Styrene (abbreviated as SIR SIROPOL) was used as a cross-linking agent in the unsaturated polyester resin. It was sourced from the Saudi Industrial Resin Co. Ltd. It is a moderately viscous liquid that may be hardened into a solid form by adding methyl ethyl ketone peroxide (MEKP), with cobalt naphthenate serving as a catalyst to quicken the solidification process. The ratio of hardener to resin is 2 percent, compared to 0.5 percent for the accelerator.

Table 1 displays the usual characteristics of unsaturated polyester resin. And silica nanoparticles used in this study.

**Table 1.** Standard characteristics of unsaturated polyester

| Materials | Density ($g/cm^3$) | Tensile strength (Mpa) | Tensile modulus (Gpa) | Cure shrinkage % | Tg (ºK) |
|---|---|---|---|---|---|
| **UPE** | 1.05-1.4 | 23.4-89.7 | 1.1-4.5 | 5-12 | 340 |

**Table 2**. Chemical analysis of the silica used in this work.

| Oxide | Rms (grain-wise) | Weight% | Atomic% |
|---|---|---|---|
| Silica | 1.18 nm | 65.35 | 63.38 |
| O | - | 36.65 | 36.62 |

### 2.2 Preparation of Polyester Composite Cement (C) and Nano Silica ($SiO_2$)

The cement is subjected to heat treatment in an oven at a temperature of 100 degrees Celsius for one hour to remove moisture. The composite materials are prepared from unsaturated polyester, cement, and silica with a weight ratio of 50% cement and weight ratios of (0.2, 0.4, 0.6, 0.8, and 1)% silica using the Hand Lay-Out method, which can be determined by the following steps:

1. Determine the weight of the polyester.
2. Determine the weight of silica and cement.
3. Mix the contents in a glass container for a duration ranging from 3 to 5 minutes, and then place it in an ultrasonic water bath that operates with ultrasonic waves for 30 minutes at room temperature to obtain a homogeneous mixture free of any bubbles. Afterward, the curing agent is added to the polyester at a ratio of (100:2) and manually mixed for a duration ranging from 3 to 5 minutes

until the temperature of the mixture rises, indicating the start of the reaction, as shown in Table 3.

4. Pour the mixture into the mold from one side to avoid the formation of air bubbles, which can lead to sample failure. Distribute the mixture continuously and evenly until it reaches the desired level.
5. Leave the samples in the mold for a period of 7 to 10 days, then prepare the mold for heat treatment in an oven at a temperature of 60 degrees Celsius.
6. Extract the samples and prepare them. Then manually smooth the samples using different grades of sandpaper gradually to obtain a smooth and level surface. Finally, prepare them for testing.

**Table 3: Materials ratios for the of composites.**

| Sample No. | Compostion | Matrix Polymer UPE(g) | Cement Powder C (g) | Silica SiO2 (g) |
|---|---|---|---|---|
| B1 | (Pure UPE) | 100% | 0% | 0% |
| B2 | (50%UPE +50%C) | 50% | 50% | 0% |
| B3 | (50%UPE +49.8%C +0.2%GP) | 50% | 49.8% | 0.2% |
| B4 | (50%UPE +49.6%C +0.4% GP) | 50% | 49.6% | 0.4% |
| B5 | (50%UPE +49.4%C +0.6% GP) | 50% | 49.4% | 0.6% |
| B6 | (50%UPE +49.2%C +08% GP) | 50% | 49.2% | 08% |
| B6 | (50%UPE +49%C +1% GP) | 50% | 49% | 1% |

## 3.Result And Discussion

### 3.1 Field Emission Scanning Electron Microscope (FE-SEM):

Figure 1. shows FE-SEM images of the surface structure of pure UPE. The fracture surface of the pure UPE sample in the form of layers.

Fracture Surfaces SEM Analysis of Samples of PUE-$SiO_2$ 0.2% . Figure 2 shows many holes and cavities, which could be due to other small molecular chemical compounds adhered to the silica nanoparticles. Circled crack propagation in Figure 2 justices that the crack direction is from top to bottom in the micrograph. Figures 2 signify crack propagation as a result of cavities and holes formed, due to improper mixture process. white zones in FE-SEM analysis show that the deformation and cohesive failure of the composites is because of the silica sand nanoparticles surrounding a large part of the polymer matrix. The decreasing trend of mechanical properties is due to accumulation of silica sand nanoparticles in epoxy as shown in SEM results images. The particles are nearly globular in shape with an average particles size 13.45 nm for $SiO_2$ particles[7]

Figure 3. Provide FE-SEM images of Fracture Surfaces of Samples of (PUE-1 % $SiO_2$ ) particles and which appear dense and homogeneous. The particles are nearly globular in shape with an average grain size of 52.66 nm for $SiO_2$. By examining the FE-SEM images, it can be observed that the aggregation of silica particles and their distribution within the polymer matrix have led to a slight increase in tensile and compressive strength.

The presence of well-dispersed and uniformly distributed silica particles within the polyester composite can enhance its mechanical properties. The silica particles act as reinforcing fillers, providing additional strength and rigidity to the composite structure. This can result in improved tensile strength, allowing the composite to withstand greater forces without deformation or failure. Similarly, the compressive strength of the composite may also be enhanced, making it more resistant to compression forces.

It's important to note that the extent of the increase in strength would depend on various factors, such as the particle size, distribution, and the bonding between the silica particles and the polymer matrix. Even though the increase in strength may be relatively small, it still signifies the positive impact of incorporating silica particles in the polyester composite.

Overall, the FE-SEM images support the notion that the presence and distribution of silica particles within the polymer matrix contribute to the enhancement of mechanical properties , albeit to a modest extent.

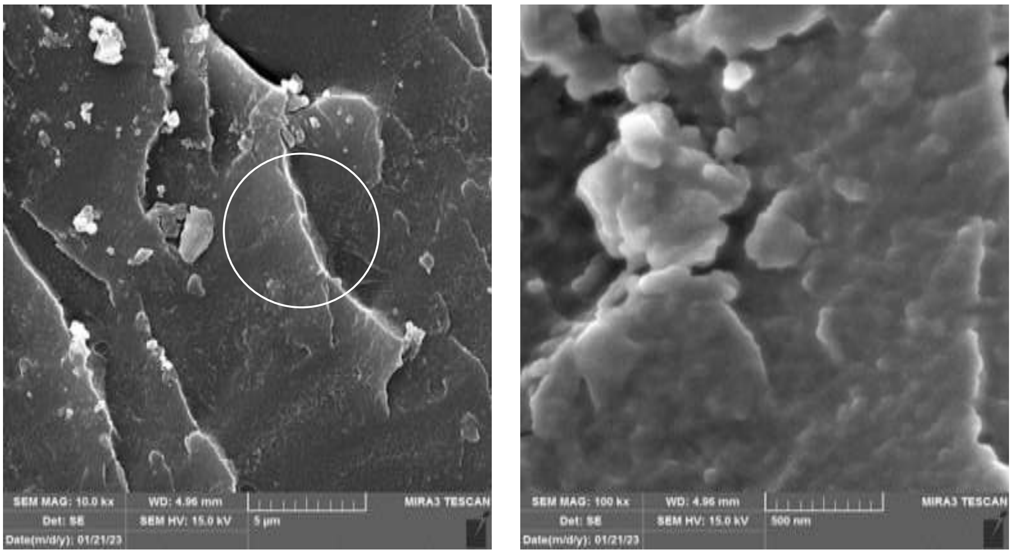


Figure 1:FE-SEM images of pure UPE

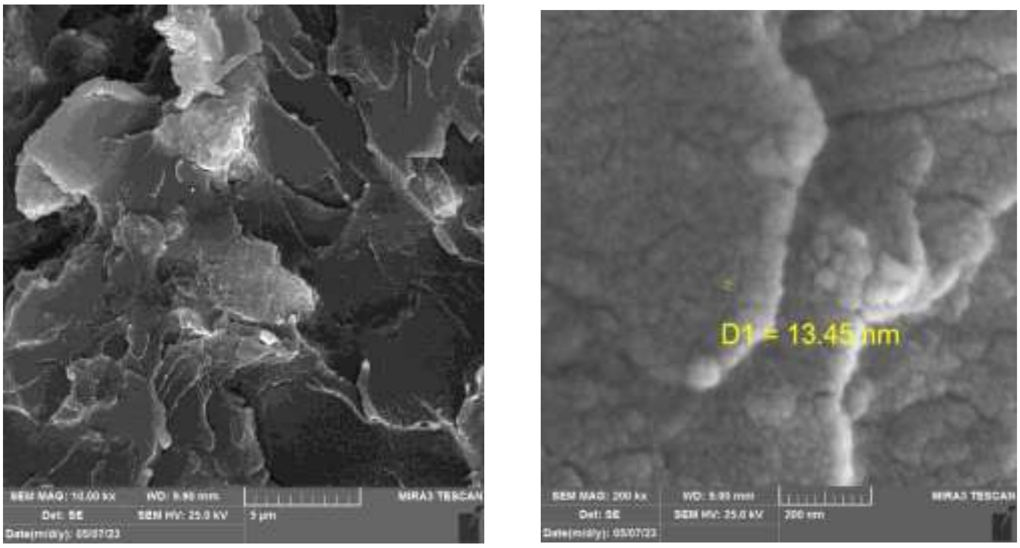


Figure 2. FE-SEM images of (50%UPE +49.8%C +0.2%GP) Composite

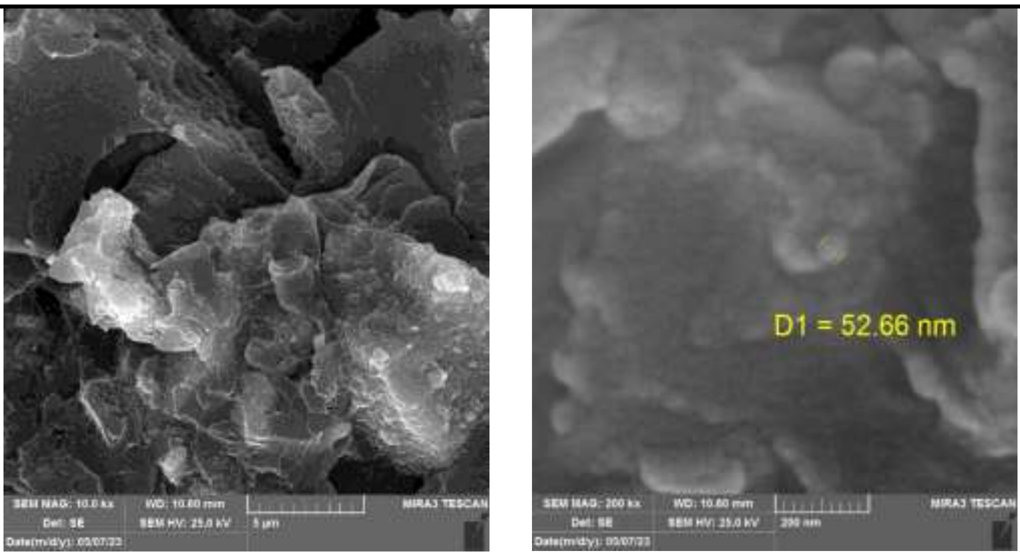


Figure 3. FE-SEM images of (50%UPE +49%C +1% GP) Composite

### 3.2 Impact Strength:

Charpy impact test was used to test the polyester and the hybrid composite .The purpose of conducting impact testing on the prepared composite materials is to assess their strength and resistance to fracture when exposed to external stress (rapid dynamic stress). The materials' ability to withstand impact forces is measured by calculating the absorbed energy and then determining the impact resistance at the fracture point, both before and after reinforcement. The initial impact resistance of the polyester material is low because polyester is a brittle material. However, after reinforcement, the impact values noticeably and variably increase. This is due to the fact that the reinforced materials bear a significant portion of the applied stress compared to the base material. The cement and silica particles distribute the applied stress over a larger area, reducing stress concentration in specific regions. Additionally, the presence of reinforcing materials prevents the formation of small cracks that occur as a result of impact. The impact resistance increases after reinforcement with silica particles ( 0.2,0.4,0.6,0.8 and 1% ) show in table (4) , as observed at point B. This is because the impact resistance of ductile and elastomeric polymers is higher than that of brittle polymers. Therefore, the increase in impact resistance is a result of the improved toughness of the material show in figure (4). There is an inverse relationship between impact values and temperature due to the breaking of bonds between the particles in the composite material and the increased sliding motion that occurs with higher temperatures. This increases the energy absorption capacity, which in turn leads to an increase in fracture toughness and, consequently, an increase in impact resistance.[8]

**Table 4. Charpy impact strength value**

| Sample | I.S k.J /m$^2$ |
|---|---|
| (Pure UPE) | 3.83 |
| (50%UPE +50%C) | 4.49 |
| (50%UPE +49.8%C +0.2%$SIO_2$) | 12.121 |
| (50%UPE +49.6%C +0.4% SIO2) | 6.951 |
| (50%UPE +49.4%C +0.6% $SIO_2$) | 6.853 |
| (50%UPE +49.2%C +0.8% $SIO_2$) | 5.483 |
| (50%UPE +49%C +1% $SIO_2$) | 7.761 |

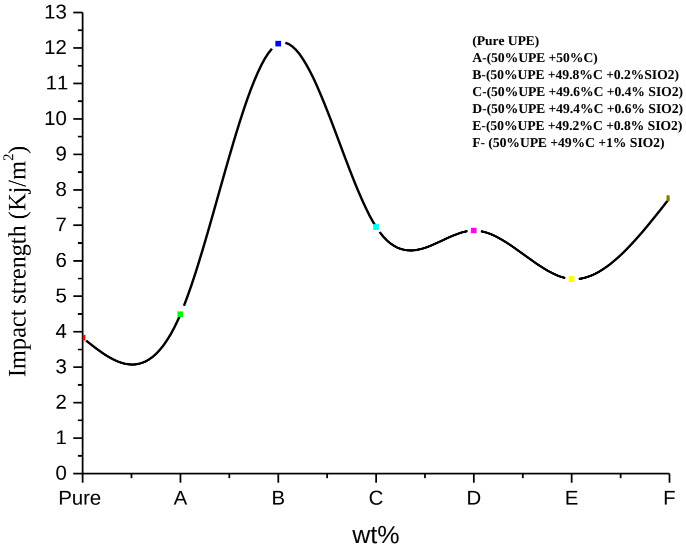


**Figure 4.** Charpy impact strength for the samples

### 3.3 Hardness Test:

The purpose of hardness testing is to measure a material's resistance to indentation and deformation. The figure illustrates the results of the hardness testing for the polymer composite and the prepared composite materials A, B, C, D, E, F. It is evident from these results that hardness increases with increased reinforcement compared to the polymer composite alone. This is attributed to the effect of the high hardness properties of the reinforcing materials, as shown in the table, compared to the polymer composite. When reinforcement is added, this property is imparted to the composite material. The presence of reinforcement materials (cement and silica) between the particles of the polymer composite impedes their movement, leading to increased surface penetration resistance in the composite material samples and, consequently, increased hardness .

It was also observed from these results that the percentage increase in hardness in composite material A (reinforced with silica only) show in figure 5 and table 5 is higher compared to the other added ratios. This difference in the increase percentage may be due to the higher hardness property of cement compared to silica. It could also be attributed to a lower adhesive material content with an increased ratio of the reinforcing material, resulting in reduced wetting of the particles in the polymer composite and thus a lack of significant increase in hardness values with increased reinforcement. These results are consistent with the findings. Additionally, the viscosity of the polymer material and the type of reinforcing material play a role in the appearance of voids in the composite material, thereby reducing its hardness.[9]

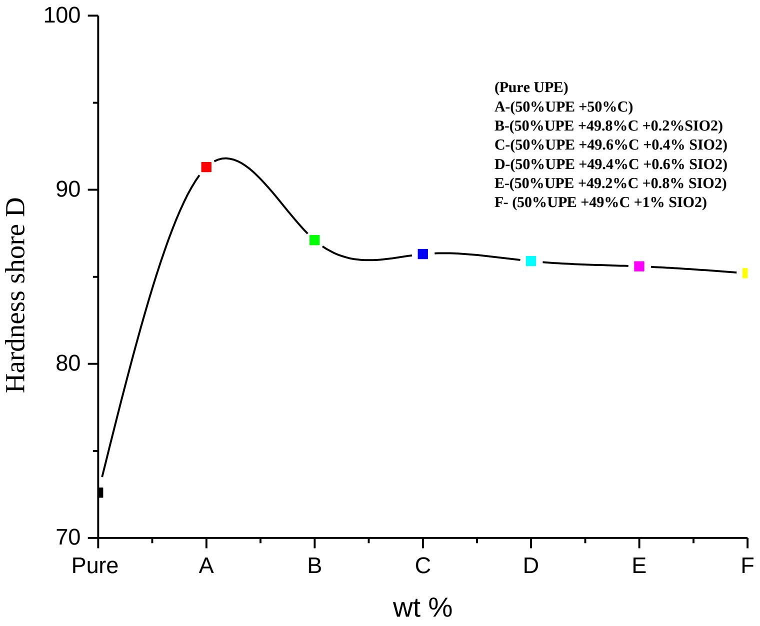


**Figure5. Hardness test UPE and their composite.**

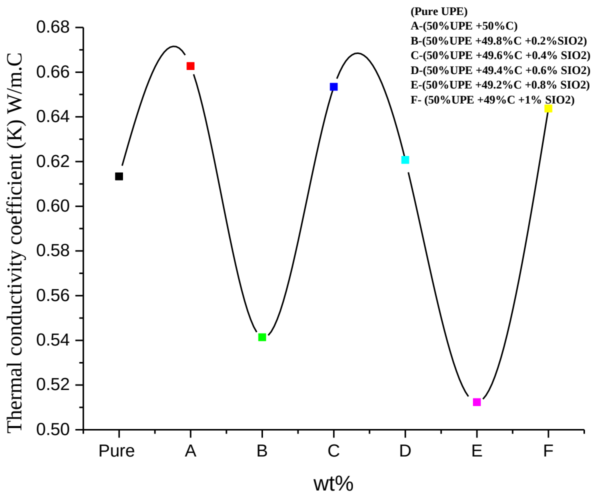
**Table 5. Hardness test value**

| Sample | Average |
|---|---|
| (Pure UPE) | 72.6 |
| (50%UPE +50%C) | 91.3 |
| (50%UPE +49.8%C +0.2%SIO2) | 87.1 |
| (50%UPE +49.6%C +0.4% SIO2) | 86.3 |
| (50%UPE +49.4%C +0.6% SIO2) | 85.9 |
| (50%UPE +49.2%C +0.8% SIO2) | 85.6 |
| (50%UPE +49%C +1% SIO2) | 85.2 |

### 3.4 Thermal conductivity:

Thermal conductivity refers to the ability of a material to conduct heat and transfer it from regions of high temperature to regions of low temperature. It represents the amount of heat transferred per second divided by the temperature difference.

From the values observed in Table (6) and Figure (6), we can observe a slight increase in the thermal conductivity coefficient value for the composite material compared to the polyester alone. Additionally, the addition of cement nanoparticles increases the thermal conductivity coefficient value. This is because cement nanoparticles have higher conductivity compared to polyester alone, although the increase in thermal conductivity coefficient is generally slight. However, the research results showed a decrease in thermal conductivity after adding silica nanoparticles to the composite (unsaturated polyester and cement). The reason for this is that the reinforcing material (silica $SiO_2$) hinders the vibrations in the internal structure of the resin, resulting in a decrease in the thermal conductivity coefficient. Additionally, polymers contain free electrons that contribute to heat transfer, as thermal conductivity relies on structural vibrations within their internal structure. These vibrations decrease when fillers are added to the polymer, hindering vibrations and thereby reducing conductivity.



.Figure 6. Thermal conductivity: of UPE and their composite

Table 6. Thermal conductivity: value of UPE and their composite

| Sample | K=w/(m.c) |
|---|---|
| **(Pure UPE)** | **0.613342** |
| **(50%UPE +50%C)** | **0.662702** |
| **(50%UPE +49.8%C +0.2%$SIO_2$)** | **0.54137** |
| **(50%UPE +49.6%C +0.4% $SIO_2$)** | **0.653431** |
| **(50%UPE +49.4%C +0.6% $SIO_2$)** | **0.620732** |
| **(50%UPE +49.2%C +0.8% $SIO_2$)** | **0.512315** |
| **(50%UPE +49%C +1% $SIO_2$)** | **0.64375** |

### 3.5 Compressive Strength:

Compressive strength refers to the maximum stress a polymer material can withstand. The compressive strength test is one of the tests that provides information about the strength of the polymer and its ability to withstand external conditions. The amount of compressive strength can be calculated at the point where the material fractures, both before and after reinforcement, using the appropriate equation.

From the above results, it is evident that the compressive strength values of the reinforced polyester are higher than those of the unreinforced polyester. This is because the reinforcing material bears most of the applied stress on the composite material. Additionally, the efficiency of the bond between the base material (polyester) and the reinforcing materials contributes to the increased compressive strength.[10]

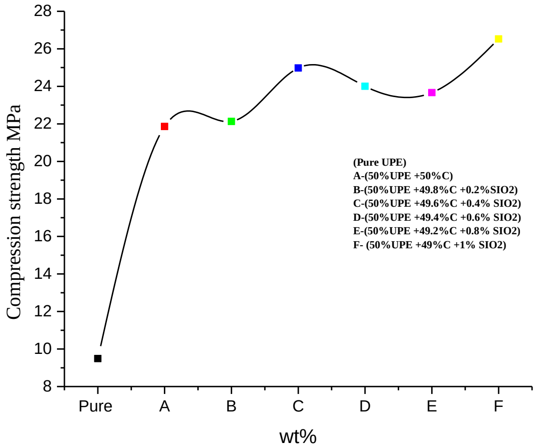


**Figure 7.** Compression Strength C.S (MPa) of UPE and their composite.

**Table 7**. Compression Strength C.S (MPa) value of UPE and their composite

| **Sample** | **C.S Mpa** |
|---|---|
| (Pure UPE) | 9.490 |
| (50%UPE +50%C) | 21.861 |
| (50%UPE +49.8%C +0.2%$SIO_2$) | 22.130 |
| (50%UPE +49.6%C +0.4% $SIO_2$) | 24.981 |
| (50%UPE +49.4%C +0.6% $SIO_2$) | 24.005 |
| (50%UPE +49.2%C +0.8% $SIO_2$) | 23.666 |
| (50%UPE +49%C +1% $SIO_2$) | 26.527 |

### 3.8 Tensile Test:

The durability of a material can be determined through the results of the tensile strength test (stress-strain) and the area under the stress-strain curve, including the fracture point. A tough material is described as strong and ductile, meaning it possesses both strength and ductility, unlike brittle materials. Brittle materials have a high yield point and strong tension, and the area under their stress-strain curve is smaller compared to that of ductile materials.

The results of the tensile strength test, illustrated in Figure (8), indicate that the cement-reinforced composite material exhibits the highest ductility among the other samples of silica-reinforced composite material with varying proportions. These samples show a longer strain before fracture compared to the others. Additionally, we observe that the area under the stress-strain curve until the fracture point is larger for this sample, and plastic deformation is evident compared to the composite material reinforced with a mixture of cement, silica, and unreinforced polyester. As for the unreinforced polyester, it is described as a brittle material that fractures rapidly without exhibiting plastic deformation before the fracture.

The enhanced toughness exhibited by the cement-reinforced composite material and the composite material reinforced with a specific ratio of cement and silica is attributed to the high tensile strength and elasticity of cement and silica. Furthermore, their homogeneous distribution within the polyester material creates strong interfacial bonding between the base material and the reinforcing material, in addition to the compatibility between the base material and the cement and silica fillers. This leads to increased tensile strength and durability, as shown in Table (8).

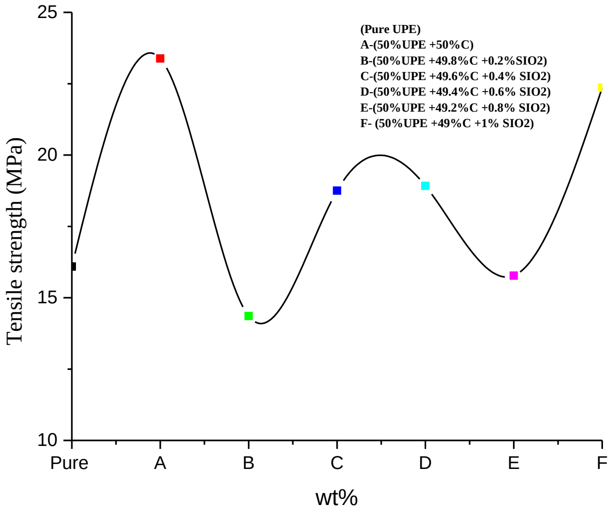


**Figure 8.** Tensile Strength T.S (MPa) of UPE and composite.

**Table 8.** Tensile Strength T.S (MPa) value of UPE and their composite

| Sample | T.S MPa |
|---|---|
| (Pure UPE) | 16.094 |
| (50%UPE +50%C) | 23.385 |
| (50%UPE +49.8%C +0.2%$SIO_2$) | 14.359 |
| (50%UPE +49.6%C +0.4% $SIO_2$) | 18.755 |
| (50%UPE +49.4%C +0.6% $SIO_2$) | 18.922 |
| (50%UPE +49.2%C +0.8% $SIO_2$) | 15.775 |
| (50%UPE +49%C +1% $SIO_2$) | 22.359 |

## CONCLOSIONS:

Based on the experimental procedure and the results obtained, the following conclusions can be drawn:

1. Incorporating silica nanoparticles into the unsaturated polyester composite improves its mechanical properties, although to a modest extent.
2. The field emission scanning electron microscope (FE-SEM) images indicate that the presence and distribution of silica particles within the polymer matrix contribute to enhanced mechanical properties.
3. The impact resistance of the composite material increases after reinforcement with silica particles. This is attributed to the improved toughness of the material and the distribution of stress over a larger area.
4. The hardness of the composite material increases with increased reinforcement, indicating the positive effect of reinforcing materials on surface penetration resistance.
5. The addition of cement nanoparticles increases the thermal conductivity coefficient of the composite material, while the addition of silica nanoparticles decreases it.
6. The compressive strength and tensile strength of the reinforced polyester are higher than those of the unreinforced polyester, indicating the efficiency of the bond between the base material and the reinforcing materials.

Overall, the experimental results demonstrate that the incorporation of silica nanoparticles and cement into the unsaturated polyester composite leads to improvements in mechanical properties, impact resistance, hardness, and compressive strength, while the thermal conductivity may be influenced by the specific reinforcing materials used.

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