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Study of some Mechanical and Physical Properties of Unsaturated Polyester Reinforced with Luffa Fibers

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Abstract

The present work employed luffa fibers (L.F.) as a means of reinforcing the matrix, which consisted of an unsaturated polyester resin. Prior to reinforcement, the fibers received an alkali treatment. The samples were created using the hand lay-up approach, with varying fiber volumetric fractions of 10%, 15%, 20%, and 25%. Following the completion of the preparatory phase, a comprehensive analysis has been conducted on several mechanical and physical properties, encompassing tensile strength, bending strength, impact strength, thermal conductivity, dielectric constant, and dielectric strength. When comparing pure unsaturated polyester resin with a composite of unsaturated polyester resin reinforced with luffa fibers at a volumetric percentage of 25%, it is shown that the latter exhibits superior mechanical properties. Conversely, the composite reinforced with 10% V.F. displays worse mechanical characteristics. The region where the highest impact resistance was measured was found to be 2.34 KJ/m2. Similarly, the maximum value of tensile strength was observed to be 17.73 MPa, while the highest value of bending strength was recorded at 14.34 MPa. Regarding the physical characteristics, the results also showed that the thermal conductivity of all samples decreased with increasing fiber volume fraction. Additionally, The results also showed that the dielectric strength decreased with increasing fiber volume fraction for all samples, as the lowest value for dielectric strength durability was 10.73 kV/mm. Furthermore, The results also showed that the dielectric constant increased with the increase in the volume fraction of the fibers for all samples, as the highest value of the dielectric constant was 1.039.. Based on the aforementioned information, it is possible to employ Luffa fibers in many structural applications that require robust mechanical, thermal, and electrical insulation properties.

Keywords: Luffa Fibers; Impact Resistance; Tensile strength; Bending Strength; Thermal Conductivity; Dielectric Constant; Dielectric Strength.

دراسة بعض الخواص الميكانيكية والفيزيائية للبوليستر غير المشبع المقوى بألياف اللوفا

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الخلاصة

يستخدم العمل الحالي ألياف اللوف (L.F.) كوسيلة لتدعيم المادة الاساس ، والتي تتكون من راتنج البولي أستر غير المشبع . قبل التدعيم ، تلقت الألياف معالجة قلوية. تم تحضير العينات باستخدام طريقة القولبة اليدوية ، مع كسور حجمية متفاوتة من الألياف تبلغ 10% و15% و20% و25% . بعد الانتهاء من مرحلة التحضير، تم إجراء اختبار شامل للعديد من الخواص الميكانيكية والفيزيائية، بما في ذلك مقاومة الشد، ومقاومة الانحناء، ومقاومة الصدمة ، والتوصيلية الحرارية ، وثابت العزل الكهربائي، و متانة العزل الكهربائي. عند مقارنة راتنج البولي أستر غير المشبع النقي مع متراكب من راتنج البولي أستر غير المشبع المقوى بألياف اللوف بنسبة حجمية

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تبلغ 25% ، فقد تبين أن الأخير يظهر خواص ميكانيكية متفوقة. على العكس من ذلك، تم تعزيز المركب بـ 10% فانه يعرض خصائص ميكانيكية أسوأ. و قد وجد ان أعلى مقاومة للصدمة هي عند ($2.34\ kJ/m^2$). وبالمثل، فقد سجلت أعلى قيمة لمقاومة الشد عند (17.73 MPa) ، في حين سجلت أعلى قيمة لمقاومة الانحناء (MPa 14.34). وفيما يتعلق بالخصائص الفيزيائية، أظهرت النتائج أيضا أن التوصيلية الحرارية لجميع العينات تنخفض مع زيادة الكسر الحجمي للألياف. بالإضافة إلى ذلك، أظهرت النتائج أيضًا أن متانة العزل الكهربائي تنخفض مع زيادة الكسر الحجمي للألياف لجميع العينات، حيث كانت أقل قيمة لمتانة العزل الكهربائي هي (10.73Kv/mm). علاوة على ذلك أظهرت النتائج أيضا أن ثابت العزل الكهربائي يزداد مع زيادة الكسر الحجمي للألياف لجميع العينات حيث بلغت أعلى قيمة لثابت العزل الكهربائي 1.039. وبناء على المعلومات المذكورة أعلاه يمكن توظيف ألياف اللوف في العديد من التطبيقات الهيكلية التي تتطلب خصائص عزل ميكانيكية وحرارية وكهربائية جيدة .

1. Introduction

When many materials are combined, they often provide composite materials that possess a distinctive amalgamation of characteristics that cannot be individually attained. [1]. The initial polymer composite fillers were primarily inorganic. As a matter of fact, synthetic fibers like glass, nylon, aramid, rayon, carbon, and polyester are frequently employed to reinforce plastics [2, 3]. The utilization of polymers has shown a significant rise in the past decade in comparison to conventional materials, owing to a multitude of factors. Polymeric materials possess numerous advantages in comparison to traditional materials, such as facile processing, reduced expenses, decreased weight, and enhanced productivity. Polymer composites are widely recognized for their advantageous combination of stiffness, lightness, toughness, and cost-effectiveness in low-scale manufacture. Furthermore, they enhance energy efficiency in the context of tools and transportation [4]. due to the strength and toughness of these fibers which is higher than matrix materials used with. Moreover, lignocelluloses natural fibers possess many properties such as cheap, strength, light in

weight, abundant and renewable. Natural fibers also utilized as usual resource in manufacturing low cost composite materials [5].

According to several sources, natural fibers are considered to present a more advantageous alternative to widely used synthetic fibers such as Kevlar, glass, and carbon. The mechanical, chemical, and physical qualities of these fibers vary based on their cellulose concentration [6]. The mechanical properties of a material are significantly influenced by the features of the interface between the fibers and the matrix. The efficacy of fibers is contingent upon the specific material and technique employed, hence necessitating the application of chemical treatments to enhance this interface [7]. The physical and chemical properties of fibers, such as their cellulose content, fabric structure, cross section and angle of the textile, and degree of polymerization, frequently serve as their defining characteristics [8]. Due to their low cost, low density, renewability, biodegradability, non-abrasive nature, low energy consumption, and use as a good heat and sound insulator, researchers have focused on the use of natural fibers as reinforcement in various matrices in an effort to find environmentally friendly reinforcements that can provide the same performance as their synthetic counterparts. The construction, automotive, and packaging industries have shown a great deal of interest in the development of novel bio-composite materials. These industries are currently searching for substitutes for artificial fiber-reinforced composites. Unsaturated polyesters have a vast array of properties and applications [9].

In this regard, the outcome of combining luffa fiber with other fibers or reinforcement was previously taken into account. For instance, Sakthivel M. et al. investigated the possibility of employing particle luffa fibers or coir as reinforcement for a polymer like polypropylene. They

discovered that the inclusion of lignocellulosic-based reinforcement enhanced the mechanical capabilities of the two materials while maintaining compatibility [10]. The impact of fiber treatment and the inclusion of SiO2 nanoparticles on the characteristics of the composite was investigated by Srinivasan C. et al. The fiber/matrix interface was found to benefit from treatment, and the mechanical properties improved with the addition of SiO2 nanoparticles [11]. Luffa fiber and groundnut shell powder were used by Panneerdhass R. et al. to strengthen epoxy resin. The reinforcement's volume fraction exhibited tensile, compressive, flexural, and impact strength [12]. Despite this, the findings of hybridizing Luffa fiber with Luffa particulates are encouraging, given the already-present synergy that arises from using the same type of reinforcement material. The benefits of fiber and particle reinforcement will also be readily used in other Asian nations. Luffa fibers have been extensively studied by Mwaikambo and Ansell [13], who discovered that they are excellent reinforcing materials for polymer-based composites due to their high tensile strength, stiffness, and water absorption capacity when compared to those of other natural fibers. Luffa fibers are used for a wide range of purposes, including the reinforcement of polymers, wastewater treatment [14], color absorption in solutions, dishwashing due to their naturally woven structure with gaps, the production of some auto parts, and footwear [15], among others. Studying the impact of Luffa fiber reinforcing and volume fractions of 10%, 15%, 20%, and 25% on some of its mechanical and physical properties is the goal of our present research.

Table I: Chemical composition of Luffa Fibers [10]

Cellulose	Lignin	Hemicelluloses	Moisture content
63 %	11.69 %	20.888 %	9.74 %

2. Materials, equipment and experimental procedure

2-1. The Matrix Material (Unsaturated Polyester)

Unsaturated polyester (UPE), which comes from Saudi Arabia, is a translucent liquid with a moderate viscosity and a density of 1.2 g/cm3. By adding a clear hardener, which is a mixture of methyl ethyl ketone peroxide (MEKP), at a ratio of 2g per 100g of resin, it can be treated to become solid. In order to hasten the curing process, a cobalt catalyst—a black liquid in the form of droplets—is additionally added at a ratio of 0.2g per 100g of resin. It starts to turn into a gelatinous substance (gel) at room temperature after 30 minutes.

Figure -1 Unsaturated polyester resin

2.2 Reinforcement Material

In this study, Luffa fibers (LFs) were successfully extracted from the Luffa plant indigenous to Iraq, specifically the Anbar Governorate, by the implementation of specialized mechanical techniques. The fibers underwent a cleaning process followed by washing with distilled water, and afterwards were subjected to drying in a hot air oven at a temperature of 100 °C for a duration of 15 minutes. Subsequently, the specimens were sectioned and arranged in a matrix configuration based on their respective volume fractions to accommodate the dimensions of the mold, as depicted in Figure (2).

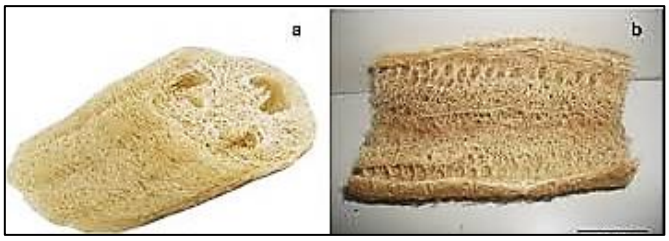

Figure-2 Luffa fiber (a) before cutting and (b) after cutting

3. Sample Preparation

The samples were Preparation using a hang-lay-up molding technique. In particular, a mold made of aluminum that had the required sample dimensions was used. For this study, the samples were prepared using the preset volume fractions (10%, 15%, 20%, and 25%). To prevent bubble formation and ensure homogeneity, the hardener and unsaturated polyester (UPE) resin were gradually mixed together with a glass rod at a ratio of 2g to 100 g. To reach a volume fraction of fibers of 10%, Luffa fibers were continually added to unsaturated polyester resin. The other volume fractions underwent the same procedure. In order to accomplish this, the volumetric fraction of the fiber (Vf) can be determined using the mathematical connection that is related to :

$$Vf = \frac{1}{1 + \frac{1-\Psi}{\Psi}\, x\, \frac{\rho_f}{\rho_m}} \tag{1}$$

$$\Psi = \left(\frac{W_f}{W_c}\right) x100\% \tag{2}$$

$$W_c = W_f + W_m \tag{3}$$

where W_f , W_m , $and\ W_C$ are the weights of the superposed material, the base material, and the reinforcement material, respectively, measured in (g).
And , $\rho_f\ and\ \rho_m$ are the density of the base material and the density of the reinforcing material, respectively, measured in (g/cm3).

The prepared metal mold is filled carefully with the composite, and the sample is then left there to cure. The sample is subjected to heat treatment after the molding process is complete, which is performed by keeping it inside a hot-air oven at a temperature of 50°C for 60 minutes. This guarantees thorough curing, enables the best possible interlocking of polymer chains, and enables the release of any tensions created during the pouring process.

4. Mechanical properties

4.1 Impact Test

A Chinese company called Large Your Testing Solution produced the testing instrument, which was used to determine the prepared materials' shock resistance using the Charpy Test. The impact resistance of the material can be ascertained by using this equipment to compute the energy needed for a fracture. The instrument primarily consists of an energy scale and a pendulum. The hammer of the gadget is raised to its highest point and fixed firmly after discharging 2.5 joules of energy. The sample is then positioned in the device's assigned location, horizontally between the supports. The pendulum is released using the lever fixed to the scale once the energy scale has been set to zero, creating a swinging motion that transforms potential energy into kinetic energy. The scale's indicator displays the sample's fracture energy (UC), which is partially lost during the sample's fracture. The impact resistance of the samples before and after testing is shown in Figure 3. The sample has the following measurements, which are in accordance with ISO 179 standard specifications: 55 mm in length, 10 mm in width, and 5 mm in thickness. The following mathematical connection is used to compute the impact resistance (I.S.) [17].

$$I.S = UC / A \quad (4)$$

Where: The fracture energy, UC, is expressed in (KJ) ،A : The cross-sectional area of the sample measured in m2.

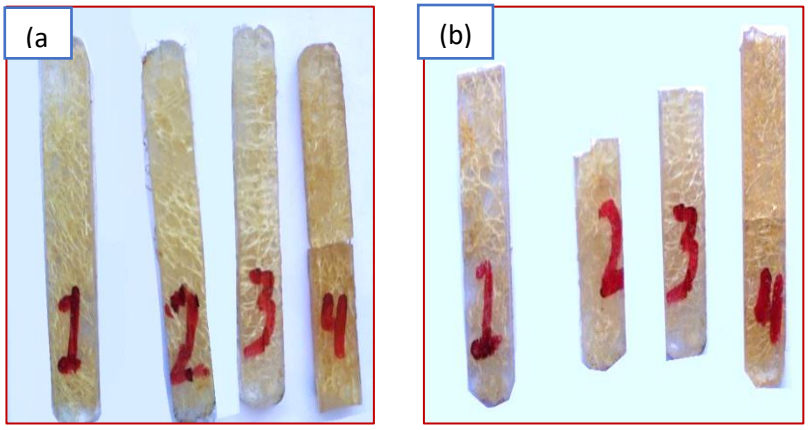

Figure-3 Impact samples, (a) before the test and (b) after the test

Figure-4 Impact resistance testing device

4.2 The Tensile Strength Test

The tensile samples were prepared according to the specifications and dimensions of the American standard (ASTM D-638-03). The examination was conducted for the prepared tensile samples using a tensile device of Chinese origin with a capacity of 50 KN of the type (LARYEE Yaur Tasting Solution), as shown in figure 5. The examination was conducted in the Advanced Materials Research Laboratory, Anbar University, College of Education for Pure Sciences, Department of Physics. Where the sample is fixed in a position designated for it in the device, specifically between the jaws, to ensure that the sample is held and fixed and that it does not move when conducting the examination, and when the device is turned on, the handles begin to tighten the sample from the top and bottom and apply a tensile force with a strain rate (mm/mmin) for all samples By using the device's graph, the results were obtained directly in curved form (stress and strain) for the purpose of calculating tensile properties.

Figure-5 Tensile strength test device

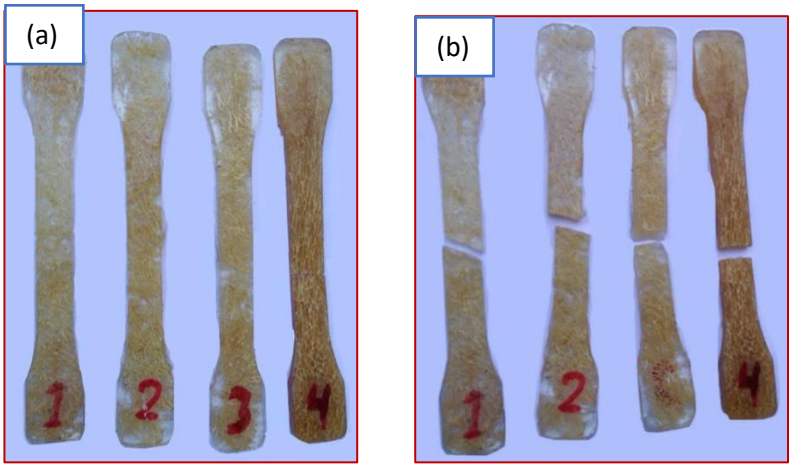

Figure-6 Tensile strength samples; (a) before the test and (b) after the test

4.3 Bending Strength Test

The device (LARYEE Yaur Tasting Solution) was used to perform the Three Point Bending Test, and it is the same device with which the above-mentioned tensile test shown in Figure 5 was tested. The test sample is fixed on two fulcrums, and then a load is gradually applied at a strain rate of (mm/min 5). As the applied load is concentrated in the middle of the sample between the two supports, the sample begins to bend, and by means of the device's

graph, we obtain the values of the bending resistance directly. The bending samples were prepared according to the international standard specifications (ASTM D-790), and Figure 7 shows pictures of the samples before and after the test.

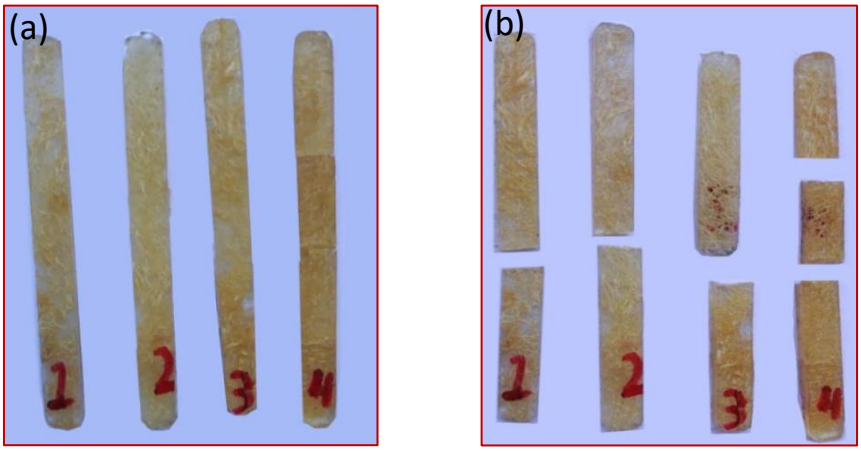

Figure-7 Bending strength samples, (a) before the test and (b) after the test

5. Physical Properties

5.1 Thermal Conductivity

The Lee's disk apparatus was utilized for this test, as shown in Figure 8. This instrument, which was created by the company (Griffen & George), was used to measure the thermal conductivity of samples of composite materials that had been developed. Thermometers were inserted into each of the three discs (TA, TB, and TC) to measure their respective temperatures in (°C). The heater transfers heat to the following disc, which it then passes on to the final disc. The following two equations can be used to get the thermal conductivity given the discs' radius (r) (mm), thickness (ds) (mm), current (I) (0.25A), and potential difference (V) (6 Volt) [18].

$$(5)K\left(\frac{T_B-T_A}{T_S}\right) = e\left[T_A + \frac{2}{r}\left(d_A + \frac{1}{4}d_s\right)T_A + \frac{1}{2r}d_S d_B\right]$$

$$H = IV = \pi r^2 e(T_A + T_B) + 2\pi re\left[d_A T_A + d_s \cdot \frac{1}{2}(T_A + T_B) + d_B T_B + d_C T_C\right] \quad (6)$$

e represents the thermal energy passing through a unit area per unit time $\frac{w}{m^2.^\circ c}$

H is the time rate at which energy is transferred to the inductance

(T_A, T_B, T_C): Disks temperature (A, B, C), respectively, C°

(d_A, d_B, d_C) : Thickness of the copper discs (A, B, C) , mm

d_s : The thickness of sample, mm . (V) : The voltage supplied to the circuit, Volt .

(r) : The radius of any of the disks, mm

Figure-8 Thermal conductivity test device.

5.2 Dielectric Constant

For static electric fields, the relative static permittivity (r) can be calculated as follows: First, the air space between the plates of a test capacitor's (Co) capacitance is computed. The capacitance C of a composite sample is then computed using the same capacitor and the distance between its plates [19].then an equation can be used to calculate the relative permittivity;

$$\varepsilon r = \frac{C}{C_0} \tag{7}$$

5.3 Dielectric strength

The purpose of this test is to assess the ability of a material to withstand the flow of electric current without experiencing a breakdown. An electrical breakdown signifies the loss of insulating characteristics in the material.Utilizing a breakdown test cell BAUR (0–60) KV outfitted with the proper electrodes, the dielectric strength was measured. tests for breakdown carried out in a transformer lubricating medium. For testing samples, the dielectric breakdown voltage was assessed at various places. It was 30°C when the test was conducted. The following equation [20] was used to get the dielectric strength:

$$E = V / t \tag{8}$$

In this context, the variables E, V, and t represent the dielectric strength, breakdown voltage (measured in kilovolts), and specimen thickness (measured in millimeters), respectively.

6. Results and Discussion

6.1 Impact Test

When Luffa fibers are used as fiber reinforcement with a volume percentage of 10% greater than the pure sample, the findings obtained and shown in Figure 9 demonstrate a significant improvement in impact resistance for all manufactured samples. The fibers' ability to lessen the key flaws in heat-molded plastics, including shrinkage during casting, brittleness, and surface fissures, is credited with explaining this improvement. As a result, the fibers improve the material's mechanical attributes, such as its resistance to impact. According to the researcher's findings in [21], the momentum of the fibers also causes the intermolecular connections to become stronger under high loads, increasing the impact resistance.The other samples also improved at the other volume fractions of (15, 20, and 25%), and this improvement can be attributed to the good adhesion between the reinforcing fibers and the polymer matrix, which creates an interfacial surface and increases the material's resistance to external stresses and loads. This also enhances the material's mechanical properties, including its resistance to impacts. The manufactured material can tolerate substantially larger impact stresses thanks to the composite structure than it could without reinforcement. The impact pressures from the impact test are transferred to the reinforcing fibers via the polymer matrix, necessitating more energy for the produced material to fracture , which aligns with the research findings [18]. And the scanning electron microscope test proves the extent of good adhesion between the luffa fibers and the unsaturated polyester of the prepared samples.

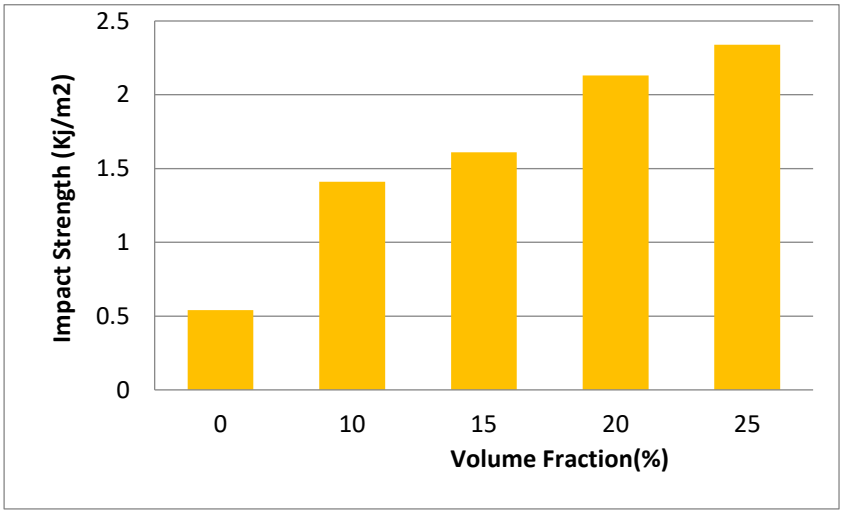

Figure-9 shows how volume Fraction and impact strength are related

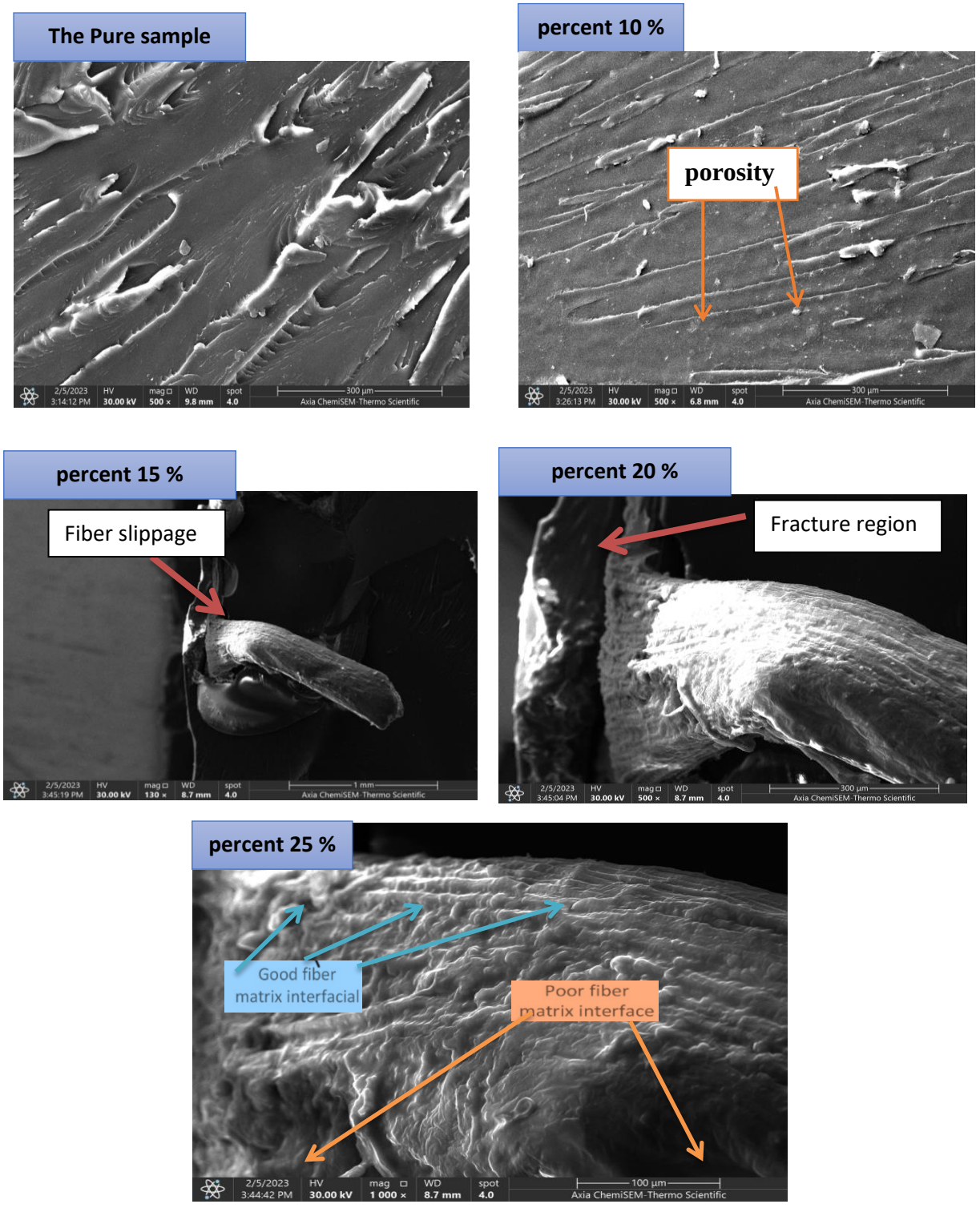

Figure-10 Scanning electron microscope images of Luffa fiber samples for different reinforcement ratios, where the fracture area and the extent of fiber slippage and bonding of the base material with the luffa are shown.

6.2 Tensile Strength Test

The results shown in Figure 11 showed that there is an improvement and a rise in the tensile strength of the samples the higher the percentage of reinforcement of these samples with luffa fibers. It moves from the matrix material to the reinforcement fibers through the interface, as these fibers work to distribute the external stress imposed on the largest size of the sample and also reduce the possibility of stress concentration on a specific area for it, and for this, the loofah fibers will work to hinder the growth of cracks that occur in samples during the tensile test, which leads to high tensile strength values for these samples as shown in Figure 8 [22]. In addition, the fibers were distributed longitudinally, so the tensile strength was as high as possible. In addition, the fibers are woven in the form of a mat, which increases the cohesion of the matrix material with the supporting material. The adhesion force between the fibers and the polyester resin has a significant effect on increasing the tensile strength.

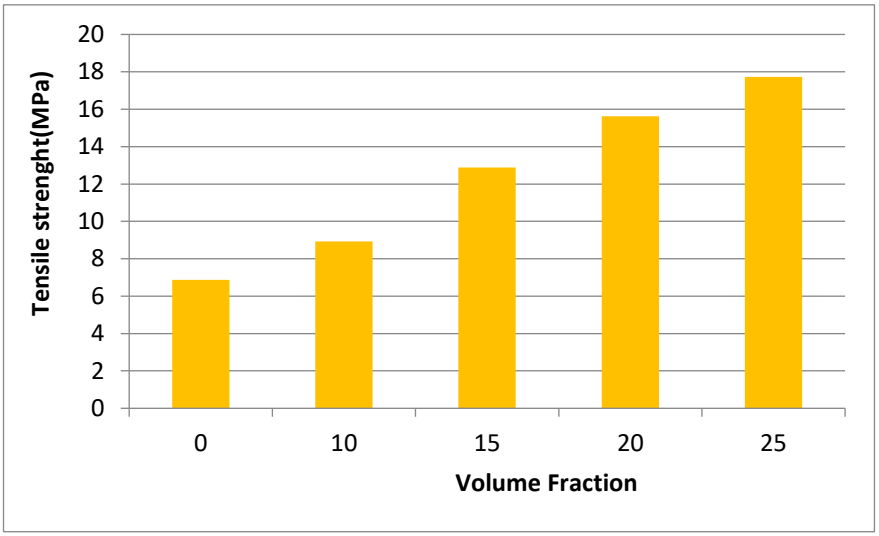

Figure-11 The relationship between volume Fraction and Tensile strength.

6.3 Bending Strength Test

The results obtained for the composites prepared from unsaturated polyester reinforced with luffa fibers indicated that the addition of fibers to the matrix material improves the bending resistance. The reason for this is that when the stress is applied to the composite material, it will be distributed to both the matrix material and the fibers, which in turn bear the largest part of it [23]. Also, the distribution of fibers on all parts of the sample makes it more cohesive with the matrix material, and this makes it more resistant to the stresses imposed on it, which leads to an increase in its bending resistance.

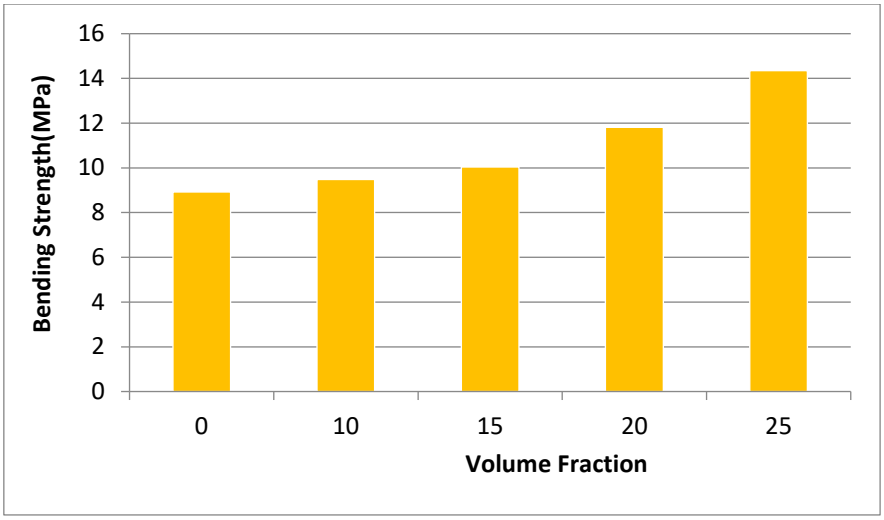

Figure-12 The relationship between volume Fraction and Bending strength

6.4 Thermal Conductivity Test

Equations (5 and 6) were used to calculate the thermal conductivity coefficient values, and this test was performed on all materials at lab temperature. According to the findings shown in Figure 11 for the samples made from unsaturated polyester resin reinforced with varying reinforcement ratios of Luffa fibers, all samples experience a decrease in heat conductivity when reinforced with Luffa fibers. The reason for this decrease is that the ability to isolate here depends on the fine fiber hairs' capacity to transfer thermal energy, as elastic waves (phonons) travel through the matrix material and the hard part of the reinforcing fibers by the vibrational movement of the atoms but encounter obstruction in the movement when they reach the capillary part of the reinforcing fibers due to the difference in the structural design of this medium.This outcome agrees with the researchers in [24], Whereas the phonons are communicated by the vibrating movement of the atoms, they discovered that the values of thermal conductivity showed a reduction with the values of the bulk fraction of the support material. As a result, when the phonons get to the support material, there is an obstacle.

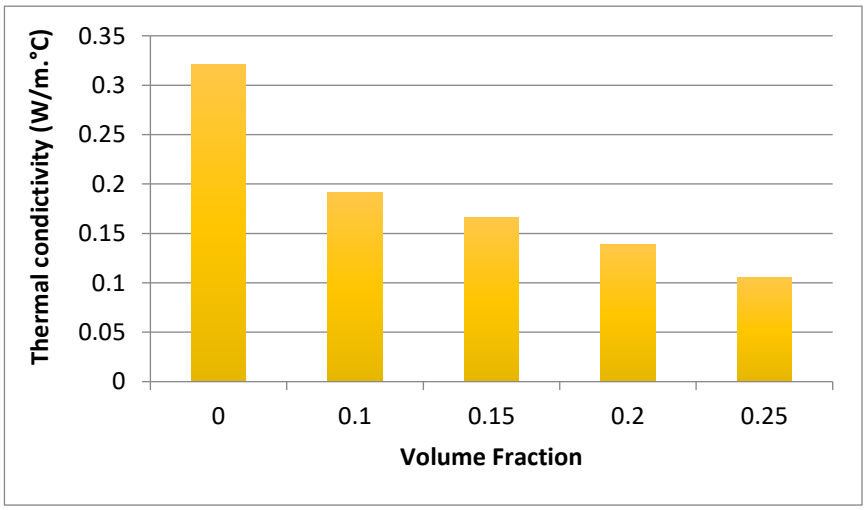

Figure-13 The relationship between thermal conductivity and volume fraction.

6.5 Dielectric Constant Test

According to the findings in Figure (14) on the dielectric constant values, all manufactured samples' dielectric constants rose when they were reinforced with luffa fibers.

This type of fiber is characterized by good insulation. As a result of the existence of the applied electric field, this leads to an increase in the ability of the electric dipoles created to keep up with the changing of the applied electric field, and as a result of the presence of these fibers, the contribution of the vacuum charge polarization relative to the total polarization will increase, as it represents a large group of charges that accumulate at crystalline defects or voids. Which leads to the generation of a local accumulation of charges that induces opposite charges on the other side, leading to the creation of dipoles in the material, which leads to an increase in the dielectric constant by increasing the reinforcement ratios , which is in line with the findings of the researcher in [25] Where it was discovered that the dielectric constant values for reinforced fiber increased as the volumetric fraction did.

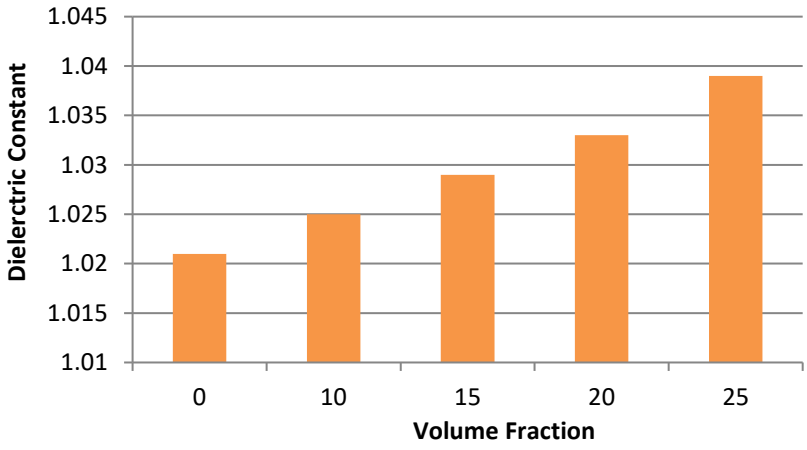

Figure-14 The relationship between volume fraction and dielectric constant

6.6 Dielectric strength test

The strength of electrical insulation reduces for all samples when reinforced with luffa fibers, according to the results displayed in Figure 15. Due to electrical breakdown and the emergence of the effect of penetration and cracking in the insulator, which depends on the voltage frequency and the long impact time, leakage currents increase with an increase in reinforcement rates. Despite the fact that polymers like unsaturated polyester resin are poor electrical conductors, they can become charged bodies with stable charges as a result of the electrical breakdown. The electric potential works on the emergence of moving charges within the superimposed sample that are able to move from one side to the other, and the source of these charges is either from within the composite material as a result of its liberation from its stability due to the energy acquired from the applied electric field, or it may be a result of the transmission of electric charges through the moisture that acts as carriers for these charges, which is in line with the findings of the researcher in [26]. It is observed that the manufactured composites' value for this attribute is lower than that of polyester in its purest form .

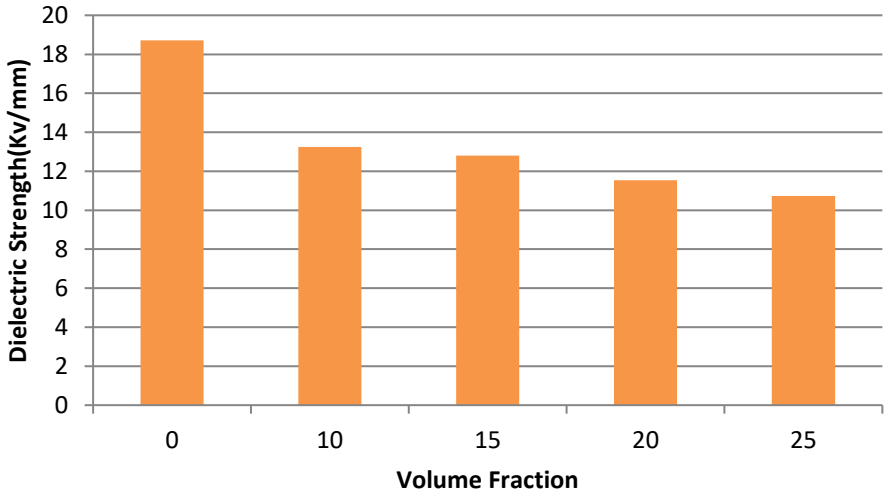

Figure-15 The relationship between volume Fraction and dielectric strength

7. Conclusion

An increase in impact, flexural, and tensile strength, particularly at reinforcing volumetric fractions of 25% .The insulator composite's behavior was shown by the thermal conductivity result. The influence of the current filler polar group causes the dielectric constant to rise and the dielectric strength to decrease. The 25% Vf-reinforced composite had good mechanical, thermal, and electrical properties. Depending on the above outcomes, the Luffa fibers can be exploited in some mechanical applications requiring high mechanical properties and good thermal insulation properties.

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