Enhancing Mechanical and Thermal Properties of Unsaturated Polyester Composites Through Sidr Leaves' Particle Reinforcement

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ABSTRACT

The Sidr Leaves Powder (SLP) is full of natural renewable, and cost-free energy resources with excellent heat resistant properties. Mixing natural fillers in conjunction with unsaturated polyester increases the mechanical and thermal features of composites, which eliminates or reduces the need for additional binders. This study probes the outcomes of supplementing Sidr Leaves Powder at different filler concentrations on the mechanical properties (durability, compression, and impact) as well as thermal conductivity accompanied by FTIR spectroscopy characterization of unsaturated polyester composites. Samples were made using hand-lay molding procedures. The consequences reveal that the maximal impact resistance is ($2.52 kJ/m^2$), the highest hardness ($72.4 N/mm^2$), and the highest compressive strength about (48.7 MPa). Moreover, the thermal conductivity's value drops to (0.101 W/m.°C). on 25% volumetric fraction. With FTIR spectra, the evidence of alteration in the chemical content and molecular structure of nanocomposites with varying filler content emerged, making the analysis of the composite material properties possible. These outcomes indicate the prospective usefulness of these composites in such fields as furniture manufacturing, especially in case of a couch due to their super properties.

1. INTRODUCTION

In the recent past, we have seen a significant increase in the use of polymer composite reinforcement using the ground plant materials decomposing by nature as the main component of such polymer composites. They have received attention due to the fact that they possess features not readily available in other material systems, and thus are able to contain renewable components. Composites revolving polymers as matrix are widely applied in various tasks thanks to the variety of properties, i.e., resistance to corrosion, fracture and fatigue to mention a few, high modulus and specific strength [1].

Since the beginning of time, mankind has learned to take advantage of the available resources in order to elevate their lives and the society they belong to. This expands research into the materials that bring out improved functionalities as compared to the conventional materials. This research has led to one equally noteworthy result, such as innovative composites like metal matrix composites, ceramic matrix composites, and polymer composites. These materials have shown that they fit the consumer demand and that they can replace the traditional materials used as raw materials in several industrial applications [2].

However, although the development of composite materials has progressed rapidly, there has been limited success with the utilization of natural fiber or particle reinforcement in polymeric composites. On the other hand, polymeric materials, when blended with the natural fillers, can produce a combination of outstanding features in a sort of mechanical character close to that of steel. Now that the focus is made on raw materials exploitation, it has contributed to the development of new compounds with properties of a specified scope which are applied in various locations [3].

A high level of demand for filler and natural fiber reinforced polymers can be explained by their easy ability for application and low cost along with some of the fillers considered to be wastes. Composite materials with fillers such as eggshells and coconut shells are another green subject, which recently have shown positive effects in stiffness and heat resistance as well as their other mechanical properties [4, 5]. An important component of the modern research activity is to investigate the usage of cellulose-based fillers, such as coconut shell, wood, and others, as substitutes for synthetic counters in thermal plastic and thermoset polymer composites. This primary goal would provide the means for cost reduction, improved efficiency during manufacturing, and the development of products with superior mechanical properties [5]. Besides these exercises, some ongoing research activities have targeted wood, Piniella Leaves, and palm kernel shell as the cellulose fillers to substitute synthetic fillers in thermoplastics and thermosets [6].

The effect of the raw and naturally treated coconut shells on the mechanical and thermal properties of unsaturated polyester composites was observed, shedding light on the stark

differences in their flexibility and temperature resistance. The existing research intends to judge extensively the mechanical and physical features of olive leaves powder incorporated unsaturated polyester [7]. The influence of Olive Leaves Powder (OLP) on the elasticity and strength of heat-induced surimi gel was examined. OLP added to surimi has shown immense increase in the tensile properties such as breaking stress and breaking strain of the thermal gel. This resulted in increasing the breaking strength which was caused by these extra crosslinks and non-disulfide covalent bonds. Their ability to strengthen the mechanics of the surimi gel products makes the OLPs' prominence as a functional ingredient highly visible, especially in products where the color is not the main focus [8].

In response to this progression, the objective of this study is to conduct research on the mechanical and physical attributes of the UPS reinforced with powdered Sidr leaves. The effect of using powerful fibers of powdered Ziziphus spina-Christi bark on the mechanical characteristics of epoxy resin was studied in the previous research. Subsequently, significant increase in mechanical properties was observed. Nevertheless, the right content of reinforcement is still subjected to further research, and some studies reported that the particular properties decrease with the addition of filler at high concentrations [9].

Additionally, incorporation of Sidr Leaves Powder (SLP) as a reinforcement to unsaturated polyester composite presents an environmentally beneficial route for materials replacement. This study will be focused on the influence that the introduction of SLP exert on the mechanical and thermal properties of composites, which could be less harming to the environment and thus environmentally friendly manufacturing approaches would be promoted. The outstanding characteristics of SLP composites propose them for the substitution of conventional substances in the field of production of furniture and construction, leading to sustainability effort in the industry.

2. MATERIALS AND METHODS

2.1 Matrix material

The primary material utilized in this exploration is unsaturated polyester (UPE) which has a low viscosity and a density of about 1.2 g/cm³. The liquid polyester was solidified by the transparent hardener which was made of methyl and ethyl ketone peroxide at a ratio of 2g per 100 g of the resin. Further on this, a cobalt catalyst, which could be referred to as a dark liquid of particle form, was added to the resin at the rate of 0.2g per 100 gram of resin. Initially at room temperature, within thirty minutes, the gelation process gains momentum and the substance begins to resemble a gel-like material.

2.2 Reinforcement material

The local Sidr Leaves (SL) acquired from the Sidr plant in Iraq, practically Anbar province, have been employed for reinforcement. The selection of Sidr tree leaves was based on their excellent mechanical and thermal attributes, affordable and naturally abundant, respectively. Sidr leaves were washed completely by distilled water then they were dried in hot air oven at 100°C for 25 minutes. Consequently, the leaves would be cut and ground into power, which was to be placed in the mold of that particular volume fraction printed in Figure 1.
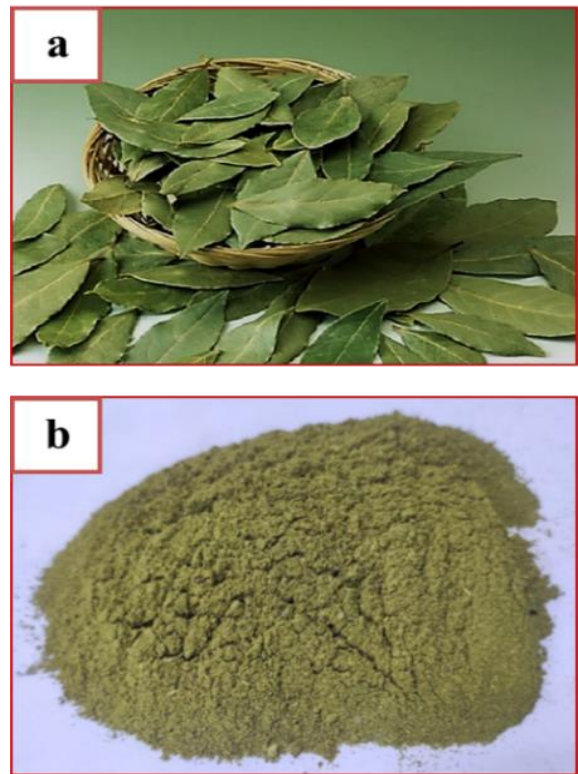

Figure 1. Sidr leaves a) Before grinding b) After grinding

2.3 Sample preparation

The samples were fabricated employing. the hand lay-up molding technique. The mold was made of aluminum and had the required dimensions. The making process was accomplished based on previously arranged volume fractions, such as 5%, 10%, 15%, 20%, and 25%, for this specific research.

The (UPE) resin was blended with the hardener at a preparation of 2g to 100g with a glass rod, stirring slowly to avoid bubbles formation and resulting in the whole homogeneous solution. For the intended product, we used an unsaturated polyester resin in which the Sidr powder was added in progressive steps until 5% of the matrix volume by volume fractions of the fibers was achieved. These sequences were repeated to obtain the rest of the volume fractions. Figure 2 illustrates the preparation process of the samples.
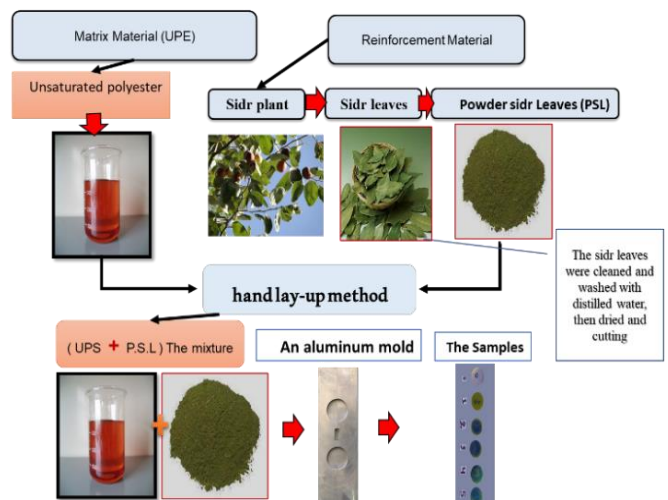

Figure 2. Process of preparing test samples

For the calculation of the volumetric fraction of Sidr powder, mathematical relationship that is connected with the weight character of the fiber (Ψ) is used as follows [10]:

$$Vf = \frac{1}{1 + \frac{1-\Psi}{\Psi} \times \frac{\rho_f}{\rho_m}} \qquad (1)$$

$$\Psi = \left(\frac{W_f}{W_c}\right) \times 100\% \qquad (2)$$

$$W_c = W_f + W_m \qquad (3)$$

where, W_f, W_m, and W_C represent the weight of the superposed material, the base material, and the reinforcement material, respectively, measured in grams. Moreover, ρ_f denote the density of the base material, whereas ρ_m the density of the reinforcing material, measured in grams per cubic centimeter.

Pouring the composite into the mold is done carefully. Subsequently, a sample is inserted into the mold in order to undergo the curing process. Following that, the sample is exposed to hot-air oven which is set to an optimum temperature of 55°C and the duration is set at 60 minutes. This type of heat treatment achieves melt curing and subsequently provides for the best overall polymer chain interlocking as well as the pressurization of any stresses generated during pouring.

3. MECHANICAL TESTS

3.1 Impact test

The Charpy Test was performed which is a traditional apparatus utilized for determining the shock resistance of prepared samples. The firm LAREE Your Testing Solution from China manufactured the device which was used. The calculation of the energy needed for breaking the material is the key feature of the equipment which enables the assessment of its impact resistance. The clamped pendulum and the energy scale form the basis of this experimental framework.
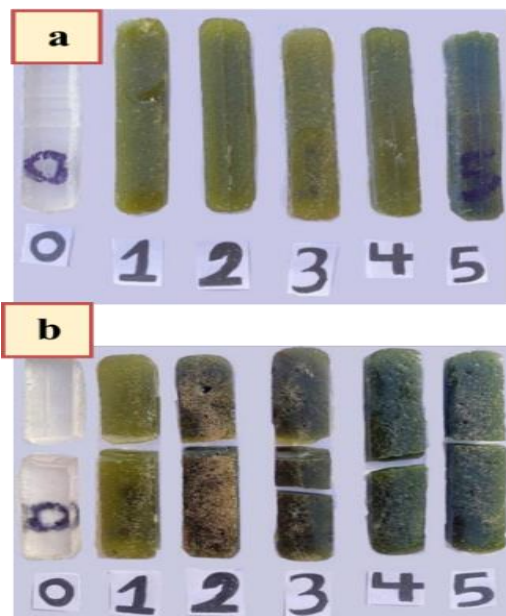

Figure 3. Impact samples a) before the test b) after the test

The technique comprises of lifting the machine's hammer to the utmost level of its force to transfer 2.5 joules of energy and temporarily sticking it in the same position to the machine's frame. Then the specimen placed in horizon way between the device's supports in the required position. With the scale set to zero, the pendulum is then unrestricted from the lever attached to the device signifying the mass is in motion as the mass of the pendulum is at a point of potential energy and therefore converted into kinetic energy. At the time of fracturing, a fraction of this energy is lost, and the recording scale shows the amount of energy this sample can withstand. Figure 3 depicts the impact resistance of samples before and after testing.

Following the (ISO 179) standard specifications, the sample dimensions are as follows: length of 55 mm, width of 10 mm, and thickness of 5 mm. The impact resistance is determined using the following equation [11]:

$$I.R = U_C /A \qquad (4)$$

where, UC represents the fracture energy measured in kilojoules (KJ)., and A denotes the cross-sectional area of the sample measured in square meters (m²).

3.2 Hardness test

The measurements of hardness were carried out with the help of the Shore D method, and specifically, by using a piece of equipment called HUATEC GROUP Hardness Tester HT-6600C Shore D manufactured by HUATEC, a Chinese company. The indenting tool, a needle-shaped one, is placed into this indenter to probes the surface and determines the hardness. With that, all hardness tests were accomplished under a room temperature of 27°C.

The samples were conducted in accordance to the international ASTM standards [ASTM-D 2240] [12], as depicted in Figure 4, which illustrates the prepared samples for hardness test. The measuring involves the determination of the surface hardness of polymer materials and its composites when reinforced in several reinforcement ratios.
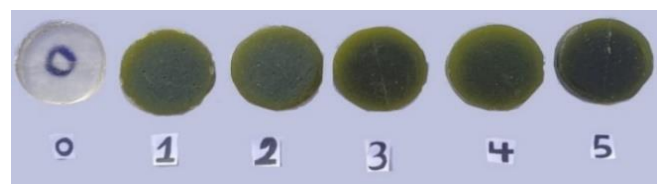

Figure 4. Hardness samples before the test

Accuracy and reliability were made by taking 10 readings for each sample and then the average of these 10 readings was used to determine the hardness value. The hardness test shows the coefficient of cohesion in the sample that indicates the resistance and endurance of the sample and thus helps in to understand the mechanical parameters. Among different types of tests, this test was carried out at a temperature of laboratory which is (27°C) to ensure identical conditions during all measurements.

3.3 Compression test

Compression strength stands for force acting against the columnar sample, which vertically extends on its ends and thus creates pressure on the ends of the sample. A σ-ε formulation

(σ-ε), where σ is the stress, ε is the strain, and E is the modulus (σ) as applied for tension force, also holds true for compression force but under compression strength reference [13].

During the compression test, a Chinese-made device supplied by Laree Technology Co. was used. It should be mentioned that Laree Tech is a Chinese developing and manufacturing company. This was the test equipment used for determination of the compression resistance of different samples under compressive load. This test in particular was performed in compression with a strain rate of 5 mm/minute.

The compressive strength was found to be directly from the readings depicted in the machine drawing as prescribed by the American standard code.

3.4 Thermal test

To accomplish the thermal conductivity test for the composites that have been prepared, a Lee's disk device (produced by Griffen & George) was utilized (Figure 5 shows the aforementioned device). This machine is used to determine the thermal conductivity by exchanging heat between the copper discs with conductivity plates (T_A, T_B, and T_C) employed to measure the temperatures in the unit, degrees Celsius (°C).
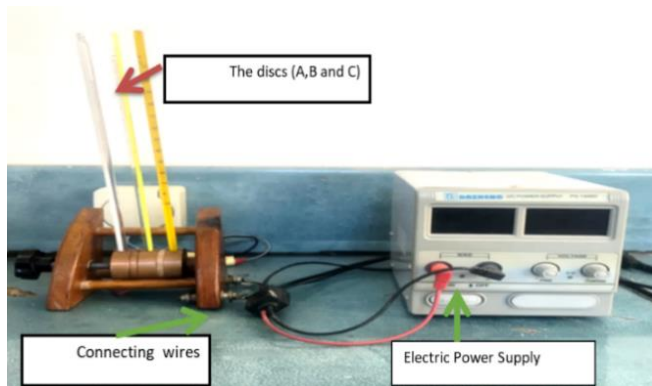

Figure 5. Thermal conductivity test device

In this investigation the hot heat is exchanged between the source heater and the first disc (T_A) then sequentially to the next discs (T_B) and (T_C). Knowing the radius of discs (r) in millimeter (mm), their thickness, respectively (d_A, d_B, and d_C) , the current (I) of 0.25A and the potential difference (V) of 6 volt , the thermal conductivity can be found by utilization of the following two formulas [14]:

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

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

where:
e: represents the thermal energy which procced through a unit area per unit time $\frac{w}{m^2.°c}$
H: 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
These equations enable a calculation of thermal conductivity through differential temperature gradients and material properties. This provides good information for thermal performance evaluation of the composite materials.

3.5 FT-IR test

A PerkinElmer Spectrum Two FT-IR Spectrometer is such a device that is chosen by many people for their research and industrial applications due to its trustworthiness and functionality [15]. Typically, the instrument's setup includes several key components such as a source to emit the infrared radiation, a sample compartment for the analysis, a beam splitter to divide the IR beam, an interferometer to modulate the beam, a detector to channel the IR signal into electrical signals, a data acquisition system and software for control, data acquisition and spectral analysis. The sample is inserted into the sampling compartment, and the instrument performs the IR scan over the wavelengths that are either within or above the specified range. The spectrum resulting from this measurement provides us with the details about the absorptions of the sample's interior components such as the wavelengths that a sample reflects each vibration at.

4. RESULTS AND DISCUSSION

4.1 Impact result

In the impact strength test, the absorbable energy at fracture for the polymer materials as well as their particle composites, which has a different reinforcing ratio, will be determined. This test gives details about their resistance to external forces from impacting. The impact distance given for each sample with varied reinforcement ratio was measured using the impact tester through the estimation of the required energy for breakage divided by the cross-sectional area of the impacted sample. The test came out at the surface temperature of the laboratory.
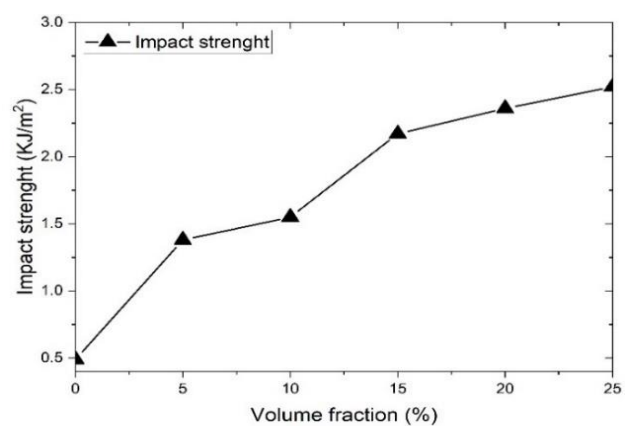

Figure 6. Impact strength of the specimens

The results, as depicted in Figure 6, reveal a significant enhancement in impact strength for all samples containing powder Sidr leaves. Specifically, the inclusion of particles as reinforcement at a volume fraction of 10% resulted in an 0.89 increase in impact strength compared to the pure sample. This increase in fracture energy of the composite materials can be

attributed to the ability of the Sidr particles to bear part of the impact stress and act as obstacles to the progression of fracture.

The connection of the particles with the medium turns out to be a major factor which influences the obstacles efficacy. Furthermore, the particles parameters and their array arrangement along the composite employed is as well a factor which is responsible for transmission the fracture through the interfaces as investigated by the scientist [9].

4.2 Hardness result

The evidence of a hardness test provides information about the material binding force and strength. Herein we used the Vickers microhardness testing method to measure the hardness of the polymer materials and their particle composites as reinforcement percentage varied. A measurement for each sample was taken, and we did the average of these measurements to find out the hardness index. The test was concluded at 28°C laboratory conditions.
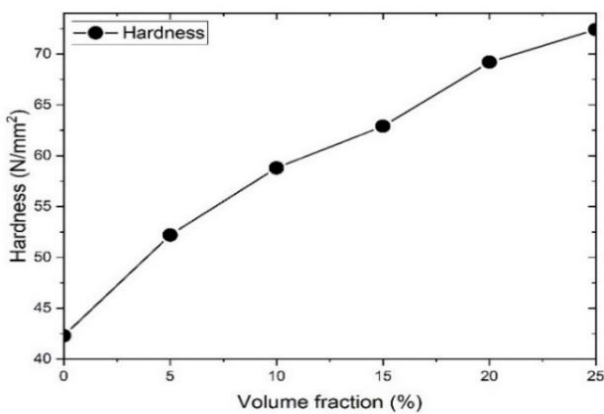

Figure 7. Hardness of the specimens

Figure 7 displays the results of the hardness test conducted on the prepared samples. It is evident that adding Sidr particles to the samples significantly enhances their hardness properties. This improvement can be attributed to the type, hardness, size, and shape of the particles added to the unsaturated polyester resin.

The recognized tendency demonstrates an increase in the hardness value for a higher volume fraction of Sidr particles. This is because the particles can pass through the space left by the polymeric chains. Now, the polymer chains are locked, and the material becomes difficult to be deformed, increasing the hardness of the material that is prepared. The researchers observed the similarity regarding their conclusion, which reveals that they shared the same point of view [16].

4.3 Compressive result

The main aim of the compressive test is to establish the maximum stress which polymeric material and samples of particles can withstand provided the vertical pressure is applied to them. After that, the stress is calculated by dividing the applied force by the area with cross-section fullwidth of the specimen. Environmental sample tubes (EST) were subjected to the external samples at the room temperature.

As illustrated in Figure 8, the compressive strength at a volume fraction of 5% began to increase by 13.1 MPa compared to the pure sample. This improvement in compressive strength can be attributed to the presence of

particles, as the load is distributed onto the particles and transferred from the base material to the particles across the interface.

Furthermore, at a volume fraction of 10%, the compressive strength improved by 8.9 MPa compared to the volume fraction of 5%. Subsequently, at volume fractions of 15%, 20%, and 25%, there was a discernible increase in compressive strength when reinforced with Sidr particles. The enhancement observed in the prepared composite materials can be attributed to the high hardness of the particles and their easy penetration into the interspaces of the polymer chains.

Such infiltration generalized to create fewer spaces for the movement of polymer chains, hence the reinforcement of the material compressed. The corresponding finding is similar to that noted earlier by the researcher [17].
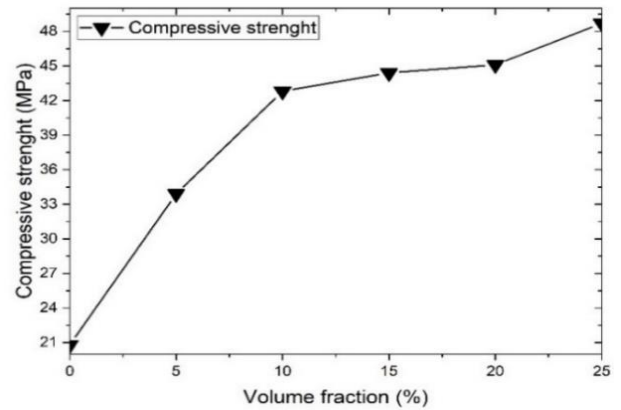

Figure 8. Compressive strength of the specimens

4.4 Thermal conductivity result

The relationship between the value of thermal conductivity and the percentage of added particles is depicted in Figure 9. It is observed that the thermal conductivity of the particles decreases with increasing reinforcement ratios.

This effect can be explained with regard to the crystal structure of a reinforcement material which consists of an arrangement of the atoms in a three-dimensional lattice [18]. The thermal conductivity of the reinforcing phase is usually lower than that of heat-convection material since the random orientation minimizes the chance of photon scattering or the formation of complex interaction structures that may accelerates thermal conductivity. They result in the opening up of the atomic contacts, which causes an obstruction to the heat transfer that acts as the barrier to heat flow.
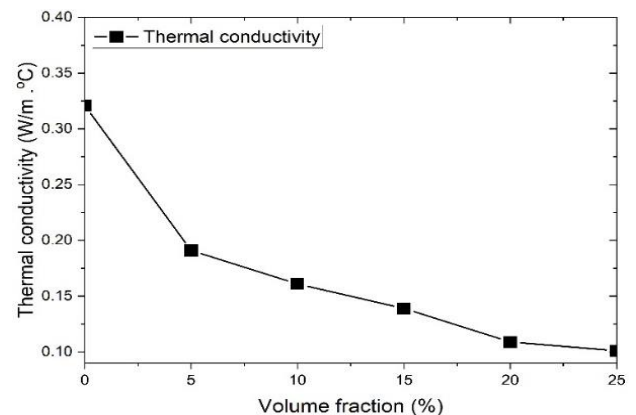

**Figure 9.** Thermal conductivity of the specimens

The observed trend in thermal conductivity with increasing reinforcement ratios aligns well with previous findings obtained by the study [19].

Sidr Leaves Powder would contribute to impeding phonon movements within the base material (UPE), and this in turn leads to thermal conductivity as the volume fraction of the powder increases.

Also, the natural crystalline structure of Sidr leaves particles gives a lower thermal conductivity than the base material (UPE), and this helps improve the thermal insulation properties of the composite.

4.5 FT-IR result

As shown in Figure 10 the FTIR spectrum of UP/LSP composites discloses predominant differences concerning the transmission spectra, especially in the area C-H bonds (2800-3000 cm^{-1}) [20]. Generally, the transmittance at the beginning of the spectra (around 400 cm^{-1}) rises when the LSP content increases (from 5% to 25%), nevertheless in the region of the C-H stretching is found a more complex behavior. The initial increment in transmittance will be due to the scattering of IR wavelengths by the LSP particles and absorption being lesser for the functional groups on the LSP particles as compared with UP. Nevertheless, with such small energy levels applied (0.49-2.52 J/m^2), it is unlikely that the process will have substantial effects on the trends observed. With this in consideration, from the expanded view of Figure 10, at 2850 cm^{-1} and 2920 cm^{-1}, respectively, exist two separate valleys attributed to the asymmetric and symmetric methylene group. The intensities of both main concentrations are related to the increasing LSP content, which contributes to the increasing number of this population within the composite. The release of certain chemicals could be what is driving this trend, with LSP containing a mixture that seems to have predominance of some CH2 environments as opposed to the more diluted one in UP. Other important role is to analyze the spectra, for example, by checking whether there are any shifts towards higher wavenumbers, which will help in the understanding of how LSP incorporation influences the FTIR spectra.
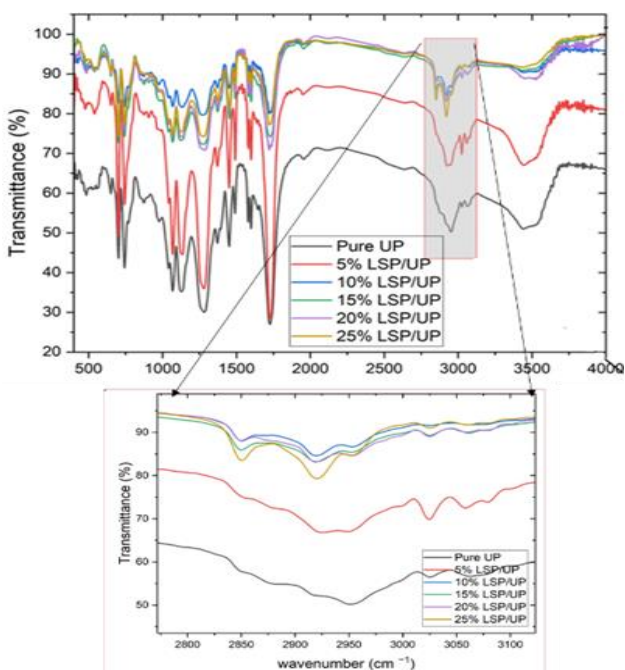
Figure 10. FTIR spectra of the specimens

The FTIR spectra also shows that there are groups of functional groups and different interactions that can enhance the thermal stability of the compound, which means that there is homogeneity and interaction between the Sidr Leaves Powder and the base material.

5. CONCLUSION

Through a broad examination of mechanical and thermal properties in relation to the Fourier Transform Infrared (FTIR) spectroscopy of the unsaturated polyester (UP) fibers embedded in Sidr Leaves Powder (SLP), there are some primary outcomes. For a start, due to additive manufacturing implementation the UP-composite matrix has been characterized by considerable mechanical upgrades that give added benefit to the such as impact resistance, hardness and compressive strength. This achievement takes its origins from the reinforcing effect of nano-materials that are scattered across the composite material forming barriers to propagation of cracks and additional load-bearing. In the next respect, thermal conductivity testing delineated the trend of a reduction in thermal conductivity with rising SLP content, which gives an indication of the composites having the capability of possessing improved thermal insulation property. Such phenomenon can be accounted for its inherent attributes, such as low heat transmission properties, which is one of those that aids SLP to facilitate to transport heat relatively less inside the material. Besides the FTIR spectroscopy, the characterization was employed for the determination of the chemical composition and the molecular structure of the composites. Multiple spectra analyses indicated changes in the transmission spectra with varying SLP quantity, the most prominent were found in the C-H stretching region, suggesting molecular environment shifts and interactions in the composite. In general, the fusion of mechanical, thermal and IR assessments signifies the promising nature of the UP/SLP composites in particular in the significant fields involving the upgraded mechanical strength, thermal insulation, and chemical disclosure. Beyond the scope of the paper, additional investigations are needed to reach the maximum capabilities of SLP blends by adjusting their compositional and processing parameters in a way that could be advantageous for various industrial applications.

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