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Synthetic Sacks as Reinforced Fibers in the Thermosetting Composites

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Abstract

This study was carried out to investigate the preparation of thermosetting polymeric blend consisting of three adhesive types, namely: epoxy, polyvinyl formal (PVF) and unsaturated polyester. Both of epoxy and PVF were used as a matrix-binder at fixed weight. Whilst unsaturated polyester was used at different weights and added to the matrix so as to produce prepared epoxy-PVF-unsaturated polyester blend. Several experiments were performed at different operating conditions, mixing speed and time at room temperature to identify the most favorable operating conditions. The optimum mixing speed and mixing time for the prepared blend were 500rpm and 5 minutes respectively.

Solid wastes-synthetic sack fibers from high volume, low cost, renewable fiber sources have been used as environmentally friendly alternatives to reinforcing fibers in composites. Many mechanical and thermal tests were carried out of the prepared blend at different weighted ratios. The optimum weighted ratio of the prepared blend for the untreated samples was characterized by the hardness and bending deflection properties and it was 0.40w/w, while for impact strength and thermal conductivity properties was 0.20w/w respectively. At these optimum weighted ratios of untreated samples with sack fibers, the maximum values of hardness and impact strength properties were 95 shore and 2.25J/cm^2 respectively. On the other hand, the minimum bending deflection and thermal conductivity properties values were found to be 4mm and 0.01094W/cm.^{o}C respectively. They showed the best bonding forces and physical interaction between two concentrations of matrix and unsaturated polyester adhesives.

Treated samples of sack fibers reinforced composites at their optimum weighted ratio showed better fiber-matrix interaction as observed from the experimental results leading to enhance and improve the mechanical (hardness, impact strength, and bending deflection) and thermal (thermal conductivity) properties when compared to the untreated sample. These improvements in treated samples with two layers of sack fibers were predominant.

Keywords: *Epoxy, polyvinyl formal, unsaturated polyester, sack fibers and thermo-mechanical properties.*

1. Introduction

Composites are materials that comprise strong load carrying material, known as reinforcement, imbedded in weaker material, known as matrix. Reinforcement provides strength and rigidity, helping to support structural load. The matrix or binder, organic or inorganic, maintains the position and orientation of the reinforcement [1].

In polymer composites, the binder material is a polymer. The binder, or matrix, surrounds the reinforcing elements which may be plates, particles or fibers and which are usually added to improve mechanical properties such as stiffness, strength and toughness of the matrix material [2, 3].

Thermoset is a hard and stiff crosslinked material that does not soften or become moldable when heated. Several types of polymers have been used as matrices for natural fiber composites [4]. Common thermosetting polymer resins are of high performance in composites which are epoxy, unsaturated polyester, vinyl ester, and phenolic [5]. Unsaturated polyester is extremely versatile in properties and applications and has been a popular thermoset used as the polymer matrix in composites. It is widely produced industrially as it possesses many advantages compared to other

thermosetting resins including room temperature cure capability, good mechanical properties and transparency [6].

The reinforcement of polyesters with fibers has been widely reported. Some of the promising systems are polyester-sisal [7], polyester-coir [8], polyester-straw [9] and polyester-cotton-kapok [10].

The mechanical properties of a natural fiber-reinforced composite depend on many parameters, such as fiber strength, modulus, fiber length and orientation, in addition to the fiber-matrix interfacial bond strength. A strong fiber-matrix interface bond is critical for high mechanical properties of composites. A good interfacial bond is required for effective stress transfer from the matrix to the fiber whereby maximum utilization of the fiber strength in the composite is achieved [11].

The composite properties were greatly influenced by the technique as well as the processing method used. Processing produces a great variation on the dimension and dispersion of the fiber within the composite. Understanding the relationship between processing and the properties of the composites is important to obtain materials with optimized performance [12]. Similar observation was found by George et al. [13] who noticed that factors like processing conditions/techniques have significant influence on the mechanical properties of fiber reinforced composites.

Detailed studies have been done on the impact resistance of short fiber reinforced composites [14, 15, 16]. They showed that the impact resistance of fiber-reinforced composite depends on fiber rigidity, interfacial stress resistance and fiber aspect ratio. The strength of the matrix, the weakest part of the material, should be related to the failure process. The involvement of fibers in the failure process is related to their interaction with the crack formation in the matrix and their stress transferring capability. The total energy dissipated in the composite before final failure occurs is a measure of its impact resistance. The total energy absorbed by the composite is the sum of energy consumed during plastic deformation and the energy needed for creating new surfaces.

Nielsen [17] observed that fibers have a significant effect on the impact resistance through the principle of stress transfer. When an impact load is applied perpendicular to the reinforcing fibers, good fiber-matrix adhesion is required for an even moderate impact strength. Impact resistance is the ability of a material to resist breaking under a shock loading or the ability to resist fracture under stress applied at high speed.

Shah [18] showed that the impact properties of the polymeric materials are directly related to the overall toughness of the material. Toughness is defined as the ability of the polymer to absorb applied energy.

Rajulu et al. [19] investigated the effect of untreated and treated bamboo fibers coating with epoxy, unsaturated polyester and their blends on the mechanical property (tensile strength). They found that the blend coated fibers had higher tensile strength. This was attributed to the hydrogen bonding between the unsaturated polyester and epoxies group. Another study carried out by Rajulu et al. [20] studied the chemical resistance and tensile strength properties of epoxy/polycarbonate blend coated bamboo fibers and suggested that these are favorable materials for making the composites.

Park et al. [21] observed an increase in the physical properties when 5% of the weight of the unsaturated polyester was used in the epoxy and unsaturated polyester blend.

Similarly Harani et al. [22] have used unsaturated polyester for toughening the epoxy resin.

The aim of the present work is to find the optimum weighted ratio of prepared blend in the weighted formula [polyester/(epoxy+PVF)] as (w/w) by using thermo-mechanical properties as well as to ascertain whether or not the three types of thermosetting-sack system can be effectively employed for making the composites.

2. Experimental Work

Materials

Three different types of chemical adhesives: epoxy, polyvinyl formal (PVF) and unsaturated polyester with technical specifications shown in table 1 as well as synthetic sacks fibers that are used in the storage of sugar, rice and flour were applied as a reinforced composite material in this work.

Methods

Preparation of Reinforced Composite Material

Sack fibers were first cleaned, washed thoroughly with tap water and left in the open air until dryness. The dried sack fibers of one layer were cut to the rectangular cross-section with a

width of 15mm, a length of 170mm and a thickness of 0.5mm to be used for the bending and impact tests, and to the circular cross-section with diameter (30mm) and thickness 0.5mm to be used for the hardness and thermal conductivity tests.

Table 1,
Technical Specifications of Epoxy, PVF and Unsaturated Polyester Resin

Epoxy Resin	Polyvinyl Formal (PVF) Resin
Compressive strength: > 72 N/mm^2 @7 days @20^{o}C BS 6319	Formaver 15/95E free
Flexural strength: > 60 N/mm^2 @35^{o}C BS 6319	Flowing powder, BDH
Tensile strength: > 25 N/mm^2 BS 6319	M.W. 24000 to 40000
Pot life: 85 minutes @20^{o}C	PVF 82%
Specific gravity: 1.04	PVOH 5 to 6%
Viscosity: 1.0 poise @35^{o}C	PVAC 9.5-13%
Min. application temperature: 5^{o}C	Viscosity in 15% solution 60/40 toluene/ethanol at 25^{o}C: 3000 to 4500cp
Unsaturated Polyester Resin	
Appearance: Transparence	
Styrene wt%:32%	
Viscosity at 25^{o}C: 1000 cp	
Specific gravity: 1.15	
Gelatinization time: 6 min.	

Preparation of the Blend

A) Preparation of Epoxy Blend

Fixed weight of epoxy resin (17.5*g*) was added to a fixed quantity of hardener (5.8*g*) and agitated at constant mixing speed (500rpm) using a stirrer (Labinco BV, model L-81, Netherland), for a constant period of mixing time (15 minutes) at room temperature.

B) Preparation of PVF Blend

Fixed weight of PVF resin (0.1*g*) in the form of solid phase (powder) was added to a fixed quantity of solvent (2.3*g*) and agitated for fully dissolving the PVF material at constant mixing speed and time (700rpm, 15 minutes) using the same stirrer at room temperature.

C) Preparation of Unsaturated Polyester Blend

Different weights of unsaturated polyester varied from (5 to 25*g*) with its varied quantities of hardeness from (0.1 to 0.5*g*) and agitated at constant mixing speed and time (500rpm, 15 minutes) using the same stirrer at room temperature.

D) Preparation of (epoxy-PVF-Unsaturated polyester) blend

All blends of epoxy, PVF and unsaturated polyester were put together and agitated thoroughly at constant mixing speed and mixing time (500rpm and 5 minutes) respectively at room temperature and divided into two portions.

These portions were directly put in moulds of tests and designated as untreated samples-without sack fibers (W.S.). Treated samples of sack fibers for one and two layers are designated as (O.S.), (T.S.) respectively and were put in tests moulds and coated until saturated with the prepared blend.

All prepared samples (untreated and treated) were left in the open air for one day at room temperature before conducting the laboratory tests.

Note that epoxy-PVF-unsaturated polyester blend is designated as a prepared blend in the weighted formula (polyester/(epoxy+PVF)) as (w/w) and it is at zero weight of polyester blend; i.e. (epoxy+PVF) blend is only designated as standard ratio (0w/w) of prepared blend in the experiments.

3. Methodology

Experiments were performed to characterize the thermo-mechanical properties of the thermosetting polymeric composites. The untreated and treated samples of the prepared blend were loaded into the instruments so as to investigate the mechanical and thermal tests. The impact strength was determined using charpy impact instrument (time testing machine, xju-22,

pendulum, time group, 2007, Inc., USA). The bending deflection was determined by using PHYWE instrument (three point bending tester according to ASTM D790). While the hardness property was determined by using W Lestor Amsler, Harkeprufer, DIN 53505, ISO R868, Shore D). On the other hand, the thermal conductivity test of prepared blend was achieved by using Lee's disk instrument (Kocyigit Electronic, DC 0-30 volt, 6 Amperes; UK). The thermal conductivity for the treated and untreated samples was calculated by using the following equations:

$$e = P/\pi r[r(T_1+T_3) + 2(d_1T_1+0.5ds(T_1+T_2) + d_2T_2+ d_3T_3]$$

$$K = e\ ds\ [T_1 + 2T_1\ (d_1 + 0.5ds)/r\ + T_2ds/r] / (T_2 - T_1)$$

Where
e = loss in heat per unit area in ($W/cm^2.^oC$)
P = supplied power in (W)
r = radius of disk in (cm)
d_1, d_2, d_3 = thickness of disks in (cm)
ds = thickness of specimen in (cm)
T_1, T_2, T_3 = measured temperatures of disks no. 1, 2, and 3 in (^oC)
K = thermal conductivity in ($W/cm.^oC$)

4. Results and Discussion

Investigation of the Optimum Weighted Ratio of Prepared Blend

Mechanical and thermal tests were carried out at different weighted ratios (0, 0.20, 0.40, 0.60, 0.79 and 0.99w/w) of prepared blend for untreated samples-without sack fibers (W.S.) to investigate the optimum weighted ratio of (epoxy-PVF-unsaturated polyester) blend.

4.1.1. Mechanical Tests

A) Hardness Test

The effect of untreated samples at different weighted ratios of prepared blend on the mechanical property, hardness in *shore* is shown in figure 1. It seems clearly that the values of hardness property of untreated samples increased from 66 to 95 shore with increasing the ratios of prepared blend from 0 to 0.40w/w and decreased to 78 shore at 0.99w/w. This behavior is due to the increase in the ratios of prepared blend from standard ratio (0w/w) to 0.40w/w which was associated with an increase in the concentration of unsaturated polyester blend that has been a good mechanical properties [6] to reach the strong chemical interaction and maximum bonding forces between two concentrations of matrix-binder (epoxy and PVF blends) and unsaturated polyester blend at 0.40w/w that represented the ability to absorb the applied energy [18]. Similar observation was found by Harani et al. [22] who used unsaturated polyester for toughening the epoxy resin. On the other hand, it can be clearly seen from figure 1 that the maximum hardness value of untreated sample occurred at 0.40w/w that is designated as the optimum weighted ratio for hardness test.

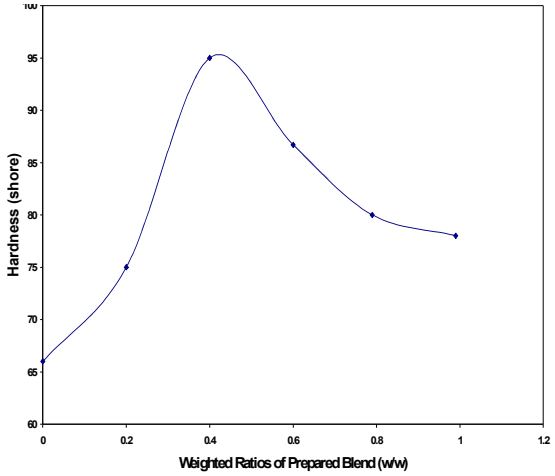

Fig.1. Effect of Untreated Samples at Different Weighted Ratios of Prepared Blend on the Hardness Property.

B) Impact Strength Test

Figure 2 shows the effect of untreated samples on the impact strength property in J/cm^2 at different weighted ratios of prepared blend. It is clear to note that the maximum impact strength value of untreated sample occurred at the weighted ratio of prepared blend of 0.20w/w. This ratio showed a better chemical interaction and maximum bonding forces between the epoxide group of the matrix-binder and unsaturated polyester blend for the three thermosetting adhesives [2, 3]. On the other hand, the addition of unsaturated polyester to matrix blend led to increase the strength of matrix and overall impact properties of prepared blend [18].The weighted ratio at 0.20w/w is designated as the optimum weighted ratio for impact strength test.

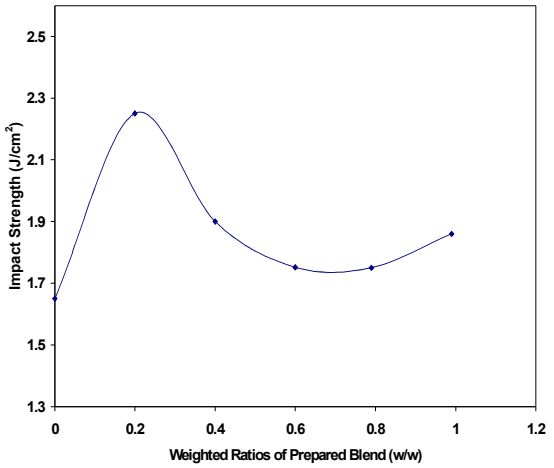

Fig.2. Effect of Untreated Samples at Different Weighted Ratios of Prepared Blend on the Impact Strength Property.

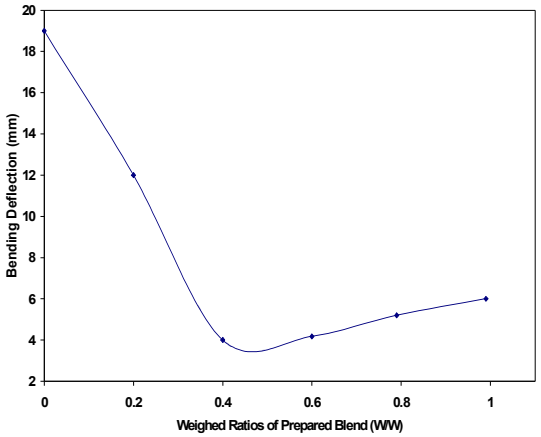

Fig.3. Effect of Untreated Samples at Different Weighted Ratios of Prepared Blend on the Bending Deflection Property.

C) Bending Deflection Test

The effect of untreated samples on the mechanical property, bending deflection in *mm*, at different weighted ratios of prepared blend is shown in figure 3. It seems clearly that the values of bending deflection property of untreated sample decreased from 19 to 4*mm* with increasing the ratios of prepared blend from standard ratio to 0.40w/w and increased to 6*mm* at 0.99w/w. It seems that the ratio of prepared blend at 0.40w/w showed a better resistance and lower bending distortion values. This can be related to the hydrogen bonding between three thermosetting polymeric adhesives of blends which promotes close packing at molecular level [19]. The results provided evidence that the prepared blend at 0.40w/w reached to the optimum weighted ratio for bending deflection test.

D) Thermal Test

Figure 4 shows the effect of untreated samples at different weighed ratios of prepared blend on the thermal conductivity property in *W/cm.°C*. It seems clearly that the maximum value of the thermal conductivity of prepared blend occurred at the weighted ratio of 0w/w; i.e. the standard ratio of prepared blend. The minimum value of the thermal conductivity of prepared blend correspond to the weighted ratio of 0.20w/w. On the other hand, experimental results showed that the thermal conductivity of prepared blend at different weighted ratios is smaller than that of standard weighted ratio. This is due to thermal resistance of unsaturated polyester adhesive that led to increase the overall thermal resistance of the prepared blend [6]. The prepared blend at 0.20w/w is designated as the optimum weighted ratio for thermal conductivity test.

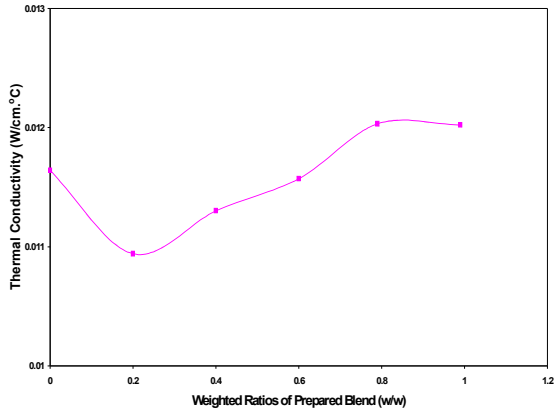

Fig.4. Effect of Untreated Samples at Different Weighted Ratios of Prepared Blend on the Thermal Conductivity Property.

Investigation of the Reinforced Composite Material

4.2.1. Mechanical Tests

A) Hardness Test

Table 2 shows the effect of untreated (W.S.) and treated samples with sack fibers (O.S., T.S.) on the hardness property at standard and optimum weighted ratios of prepared blend. At the standard weighted ratio, the percentage values of hardness for treated sample with sack fibers increased by 16 and 22% respectively compared

to that of untreated sample. While at the optimum weighted ratio, they increased by 29 and 41% respectively.

On the whole, it is observed that the treated sample with sack fibers at standard and optimum weighted ratios of prepared blend showed a better mechanical strength of the composite material and a better physical interaction with prepared blend. This result is in agreement with that reported by Nielsen [11] who attributed that to the strong fiber-matrix interface bond for giving high mechanical properties.

Table 2,
Effect of Untreated and Treated Sample on the Hardness Property at Standard and Optimum Weighted Ratios of Prepared Blend.

Weighted Ratios of Prepared Blend (w/w)	Percentage increase of hardness in (*shore*) for treated samples	
	O.S.%	T.S.%
Standard (0)	16	22
Optimum (٠.20)	29	41

B) Impact Strength Test

Table 3 shows the effect of untreated (W.S.) and treated samples with sack fibers (O.S., T.S.) on the impact strength property at the standard and optimum weighted ratios of prepared blend.

Table 3,
Effect of Untreated and Treated Sample on the Impact Strength Property at Standard and Optimum Weighted Ratios of Prepared Blend.

Weighted Ratios of Prepared Blend (w/w)	Percentage increase of impact strength in (J/cm^2) for treated samples	
	O.S.%	T.S.%
Standard (0)	9	13
Optimum (٠.40)	16	26

Compared to untreated samples, the impact strength percentage values of treated samples with sack fibers for one layer (O.S.) and two layers (T.S.) increased by 9 and 13% respectively for standard ratio. Whilst, they increased by 16 and 26% respectively for the optimum weighted ratio.

Treated samples of sack fibers with two layers (T.S.) showed better fiber reinforced composites as observed from table 3. This can be attributed to the strong physical interaction between the prepared blend of thermosetting and reinforced composite fibers that led to increase in the strength and toughness between them [14]. The sack fibers with two layers (T.S.) effect on the impact strength property was predominant. Mechanical properties of a fiber-reinforced composite depend on many parameters, such as fiber strength, modulus, fiber length and orientation, in addition to the fiber-matrix interfacial bond strength [11].

C) Bending Deflection Test

Table 4 shows the effect of untreated (W.S.) and treated samples with sack fibers (O.S., T.S.) at standard and optimum weighted ratio of prepared blend on the bending deflection in *mm*. The percentage values of bending deflection for treated sample with sack at standard weighted ratio were improved by 16 and 25% respectively compared to that of untreated sample. While at the optimum ratio, they improved by 29 and 41% respectively.

On the other hand, the treated sample with sack fibers led to enhance the bending deflection property of the treated sample for both standard and optimum weighted ratios. This is due to the excellent mechanical strength of the prepared blend and reinforced composite material. These findings are in agreement with those reported by Karnani et al [11] who showed that the mechanical properties of a natural fiber-reinforced composite depend on the fiber-matrix interfacial bond strength. A strong fiber-matrix interface bond is critical for high mechanical properties of composites. Rajulu et al. [16] found that the blend (epoxy and polyester) coated fibers (bamboo) had higher mechanical properties. They attributed that to the hydrogen bonding between the unsaturated polyester and epoxies group.

Table 4,
Effect of Untreated and Treated Sample on the Bending Defection at Standard and Optimum Weighted Ratios of Prepared Blend.

Weighted Ratios of Prepared Blend (w/w)	Percentage increase of bending deflection (mm) for treated samples	
	O.S.%	T.S.%
Standard (0)	16	25
Optimum (٠.20)	29	41

D) Thermal Test

The effect of untreated and treated samples with sack fibers on the thermal conductivity property in *W/cm.^oC* at standard and optimum weighted ratios of prepared blend is shown in table 5.

It is clear to note that the thermal conductivity of treated samples with sack fibers have lower percentage values and improved by 8 and 12% respectively when compared to those of the untreated samples. Whilst at the optimum weighted ratio, they improved by 13 and 19% respectively compared to that of the untreated sample.

It is generally observed that the improvement of thermal conductivity property for treated sample with two layers of sack fibers was predominant due to the best thermal resistance of them. This depends on processing conditions/ techniques that has significant influence on the mechanical properties of fiber reinforced composites [12, 13].

Table 5,
Effect of Untreated and Treated Sample on the Thermal Conductivity at Standard and Optimum Weighted Ratios of Prepared Blend.

Weighted Ratios of Prepared Blend (w/w)	Percentage increase of thermal conductivity (W/cm.^{o}C) for treated samples	
	O.S.%	T.S.%
Standard (0)	8	12
Optimum (٠.40)	13	19

5. Conclusions

From the results presented, it can be concluded that:

1. The optimum mixing speed for the preparation of epoxy, unsaturated polyester and prepared blends was 500rpm while for PVF blend was 700rpm. The optimum mixing time for all blends was 15 minutes; except for prepared blend, it was 5 minutes.
2. The optimum weighted ratio of prepared blend for hardness and bending deflection properties was 0.40w/w. while for impact strength and thermal conductivity properties was 0.20w/w.
3. The maximum hardness and impact strength values of untreated samples occurred at the optimum weighted ratio of prepared blend were found to be 95 shore and 2.25 *J/cm^2* respectively.
4. The minimum bending deflection and thermal conductivity values of untreated samples occurred at the optimum weighted ratio of prepared blend were found to be 4mm and 0.01094 W/cm.^{o}C respectively.
5. Experimental results showed that treated samples with sack fibers led to enhance and improve in the mechanical and thermal properties when compared to the untreated sample.
6. The mechanical and thermal properties of composite were significantly influenced by the techniques used. The improvement of treated samples with two layers (T.S.) of sack fibers for both mechanical and thermal properties is predominant.
7. Sack fibers can be used as an important source of fiber for composites and other industrial applications.
8. The above observations clearly indicate that the prepared blend of thermosetting (epoxy-PVF-unsaturated polyester) blend and solid wastes-sack fibers may be recommended as favorable materials for making the composites of three types of thermosetting-synthetic sacks system to satisfy both economical and ecological interests.

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الأكياس النسيجية كألياف تقوية مركبة مع اللواصق المتصلدة

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الخلاصة

نُفذت هذه الدراسة للتحري عن تحضير مزيج يتكون من ثلاثة لواصق بوليمرية متصلدة وهي (الايبوكسي والبولي فينيل فورمال والبولي استر غير المشبع). تم أستخدام كل من لاصقي (الايبوكسي والبولي فينيل فورمال) كرابط عند أوزان ثابتة، بينما أستخدم لاصق البولي استر غير المشبع عند أوزان مختلفة وأضيف إلى الرابط لإنتاج المزيج المحضر (الايبوكسي والبولي فينيل فورمال والبولي استر غير المشبع). نُفذت مجموعة من التجارب عند ظروف تشغيلية مختلفة (سرعة الخلط وزمن الخلط) عند درجة حرارة الغرفة لتحديد أفضل الظروف التشغيلية. وقد وجدت أفضل سرعة وزمن خلط للمزيج المحضر عند (500rpm و٥ دقائق) على التوالي.

تم استخدام النفايات الصلبة (ألياف ألأكياس النسيجية) المتواجدة بكميات وفيرة وقليلة الكلفة ومصدر متجدد للألياف كصديق للبيئة وبديل لألياف التدعيم في المواد المتراكبة. أجريت العديد من الاختبارات الميكانيكية والحرارية للمزيج المحضر عند نسب وزنيه مختلفة. حُددت أفضل نسبة وزنيه للمزيج المحضر عن طريق خواص (الصلادة وتشويه الانحناء) للنماذج غير المعاملة، وقد وُجدت (٠.٤٠w/w). بينما وُجدت لخواص (قوة الصدمة والموصلية الحرارية) عند (0.20w/w). عند هذه النسب الوزنيه المثالية للنماذج غير المعاملة، وجدت أعلى قيم لخواص (الصلادة وقوة الصدمة) للمزيج المحضر عند (95*shore* و$2.25 J/cm^2$) على التوالي. بينما وجدت اقل قيم لخواص (تشويه الانحناء والموصلية الحرارية) عند (4*mm* و ٠.٠١٠٩٤$W/cm.^oC$) على التوالي. أظهرت هذه الخواص أفضل قوى ترابط وتجاذب فيزيائي بين لاصقي الرابط (الايبوكسي والبولي فينيل فورمال) والبولي استر غير المشبع.

أظهرت النتائج العملية للنماذج المعاملة بألياف ألأكياس النسيجية عند نسبها الوزنيه المثالية أفضل قوى ترابط بين اللواصق والألياف والتي أدت إلى تعزيز وتحسين الخواص الميكانيكية (الصلادة وقوة الصدمة وتشويه الانحناء) والحرارية (الموصلية الحرارية) مقارنة مع النماذج غير المعاملة. هذه التحسينات التي طرأت على النماذج المعالجة باستخدام طبقتين من ألياف ألأكياس النسيجية كانت هي السائدة.