COMPARISON OF THE USE OF SACKS AND COMMERCIAL CARBON FIBERS TO IMPROVE THERMO -MECHANICAL PROPERTIES OF (EPOXY – POLYVINYL FORMAL) RESINS BLEND[+]

مقارنة استعمال ألأكياس المحاكة وألياف الكربون التجارية في تحسين الخواص الميكانيكية والحرارية لمزيج لواصق (الايبوكسي–البولي فاينيل فورمال)

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Abstract:

This research is focused on the development of new method for applying the solid wastes (sacks) from high volume, low cost, renewable fiber sources as reinforcing material for blend consists of epoxy resin as the matrix-binder at fixed weight and different weights of polyvinyl formal (PVF) as additive resin. The experimental results of sacks were compared with commercial carbon fibers to improve the mechanical and thermal properties of prepared (epoxy-PVF) blend.

Several experiments were carried out to investigate the optimum operating conditions (mixing speed and mixing time) for the preparation of (epoxy-PVF) blend at room temperature to achieve an optimum performance. The optimum mixing speed and time were 700 rpm and 15 minutes respectively.

The optimum weighted ratios of prepared blend were characterized by the hardness, impact strength, bending distortion, bending deflection and thermal conductivity properties for the nonreinforced samples with sacks and carbon fibers that found (0.21, 0.10, 0.16, 0.16 and 0.10 weight of PVF in (*g*)/weight of epoxy in (*g*) as w/w) for each property respectively. These ratios showed the best chemical bonding forces between epoxy and PVF resins. The maximum values of hardness and impact strength properties for nonreinforced samples occurred at the optimum weighted ratios of prepared blend were found 82*shore* and 2.15J/cm^2 respectively. While the minimum bending deflection and thermal conductivity values of nonreinforced samples occurred at the optimum weighted ratios of prepared blend were found 16*mm* and 0.01159$W/cm.^oC$ respectively.

Experimental results showed that reinforced samples with sacks and carbon fibers leading to enhancement in the mechanical and thermal properties and clearly improvement when compared to the nonreinforced samples. The improvement of reinforced samples with sacks for mechanical and thermal properties was predominant compared to the commercial carbon fibers.

Keywords: epoxy, polyvinyl formal, sacks, carbon fibers and thermo-mechanical properties.

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المستخلص:

ركز البحث على تطوير طريقة جديدة باستخدام النفايات الصلبة (ألأكياس المحاكة أو المنسوجة) المتواجدة بكميات وفيرة وقليلة الكلفة ومصدر متجدد للألياف كمادة لتقوية مزيج يتكون من لاصق الايبوكسي كرابط عند وزن ثابت مع أوزان مختلفة من اللاصق المضاف (البولي فاينيل فورمال) ومقارنة نتائجها العملية مع أليـاف الكربون التجارية في تحسين الخواص الميكانيكية والحرارية للمزيج المحضر (الايبوكسي- البولي فاينيل فورمال).

نُفذت مجموعة من التجارب للتحري عن ظروف التشغيل المثلى (سرعة الخلط وزمن الخلط) في تحضير مزيج (الايبوكسي- البولي فاينيل فورمال) عند درجة حرارة الغرفة من اجل الوصول إلى الأداء الأمثل. وقد وجد أن أفضل سرعة وزمن خلط عند 500 دورة/دقيقة ولمدة ١٥ دقيقة على التوالي.

حُددت أفضل نسب وزنية مثالية للمزيج المحضر عن طريق خواص (الصلادة وقوة الصدمة وتشوه الانحناء وانحراف الانحناء والموصلية الحرارية) للنماذج غير المدعمة (بالأكياس المحاكة أو ألياف الكربون). وقد وُجدت ٠,٢١، ٠,١٠، ٠,١٦، ٠,١٦ و٠,١٠ وزن البولي فاينيل فورمال (غم)/وزن الايبوكسي (غم) لكل خاصية على التوالي، والتي أظهرت أفضل قوى ترابط كيميائي بين لاصقي الايبوكسي والبولي فاينيل فورمال.

أعلى قيم لخواص الصلادة وقوة الصدمة للنماذج غير المدعمة كانت عند النسب الوزنية المثالية للمزيج المحضر، وقد وجدت 82 شور و2.15 جول/سم^{2} على التوالي. بينما اقل قيم لتشوه الانحناء والموصلية الحرارية للنماذج غير المدعمة كانت عند النسبة الوزنية المثالية للمزيج المحضر، وقد وجدت 16 ملم و ٠,٠١١٥٩ واط/سم.م$^{\circ}$ على التوالي.

بينت النتائج العملية بان النماذج المدعمة بالأكياس المحاكة أو ألياف الكربون أدت إلى تعزيز في الخواص الميكانيكية والحرارية والتي تحسنت بشكل واضح مقارنة مع النماذج غير المدعمة. إن التحسن الذي طرا على الخواص الميكانيكية والحرارية للنماذج المدعمة باستخدام ألأكياس المحاكة كان هو السائد مقارنةً مع ألياف الكربون التجارية.

Introduction:

Composites materials consist of two or more constitutes with physically separable phases. In polymer composites, the binder material is a polymer. The binder, or matrix, surrounds the reinforcing elements may be plates, particles or fibers and are usually added to improve mechanical properties such as stiffness, strength and toughness of the matrix material [1-2].

Polymer matrices for high performance composites are often thermosets. Common thermosetting resins are vinyl ester, unsaturated polyester, epoxy and phenolic [3].

Reinforcement provides strength and rigidity, helping to support structural load [4]. The 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. 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 [5].

Detailed studies have been done on the impact resistance of short fiber reinforced composites [6, 7, 8]. 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 the energy consumed during plastic deformation and the energy needed for creating new surfaces.

Rajulu et al. [9] 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. Another study carried out by Rajulu et al. [10] who 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 hydroxyl end group of the unsaturated polyester and the epoxide group of the epoxy which promotes close packing at molecular level.

Park et al. [11] observed an increase in the physical properties when 5% by weight of unsaturated polyester was used in the epoxy and unsaturated polyester blend. Similarly Harani et al. [12] have used unsaturated polyester for toughening the epoxy resin.

The aim of the present work was to find the optimum weighted ratio of prepared (epoxy-PVF) blend in the weighted formula [weight of PVF in *g*/weight of epoxy in *g*] as (w/w) using the thermo-mechanical properties. In addition to assess whether prepared blend sacks system can be effectively used for making the composites.

Experimental Work

Materials

(1) Two different types of chemical resins, epoxy with its hardener and polyvinyl formal (PVF) with its solvent at technical specifications as shown in table 1 were used in this work.
(2) Sacks as well as commercial carbon fibers were used as reinforced materials.

Table 1: Technical specifications of epoxy resin and its hardener as well as PVF resin and its solvent

Epoxy resin	Polyvinyl Formal resin
Compressive strength: > 72 N/mm^2 at 7 days @20^oC BS 6319	Formaver 15/95E free
Flexural strength: > 60 N/mm^2 at 35^oC BS 6319	Flowing powder, BDH
Tensile strength: > 25 N/mm^2 BS 6319	M.W. 24000 to 40000
Pot life: 85 minutes at 20^oC	PVF 82%
Specific gravity: 1.04	PVOH 5 to 6%
Viscosity: 1.0 poise at 35^oC	PVAC 9.5-13%
Min. application temperature: 5^oC	Viscosity in 15% solution 60/40 toluene/ethanol at 25^oC: 3000 to 4500cp
Quickmast 105 Hardener	N. N. Dimethyl Formamaid $HCON(CH_3)_2$ Solvent
Ayla construction chemicals under license from DCP, England.	Assay analysis 99% M.W. 73.09, Sigma, USA.

Methods

(1) Preparation of reinforcing materials

The solid wastes (sacks) were cleaned, washed with tap water and left in open air for one day until dryness. The dry sacks of one layer were cut for different shapes of two

rectangular cross-section with width (10, 15*mm*), length (125, *170mm*) and thickness (0.5*mm*) that are used for bending and impact tests and two circular cross-section with diameter (30*mm*) and thickness (0.5*mm*) that are used for the hardness and thermal conductivity tests. On the other hand, the carbon fibers with commercially specifications were used directly as reinforcing material in the experiments.

(2) Preparation of the (epoxy-PVF) blend

To prepare epoxy resin, fixed weight of epoxy (35*g*) used as a matrix-base was added to a fixed quantity of hardener (11.6*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 (25^{o}C).

To prepare PVF resin, different weights of PVF material in the form of solid phase varied from (0.1 to 0.5*g*) with its varied quantities of solvent from (2.3 to 11.5*g*) were agitated for fully dissolving the PVF material at constant mixing speed (700rpm) using the same stirrer for a fixed period of mixing time (15 minutes) at room temperature.

Each prepared resin of epoxy and PVF was agitated thoroughly at constant mixing speed and mixing time as 500rpm and 15 minutes respectively at room temperature to prepare (epoxy-PVF) blend. The prepared blend at each of weighted ratios of (0.00, 0.05, 0.10, 0.16, 0.21 and 0.26w/w) was divided into four portions.

These portions were put directly in moulds tests and designated as nonreinforced samples. The reinforced samples of sacks and carbon fibers were put in moulds tests and coated until saturation with the blend.

All prepared samples (nonreinforced and reinforced) were left in open air for one day at room temperature before being conducted the laboratory tests.

Note that, epoxy-PVF blend is designated as prepared blend (PVF/epoxy in weighed formula in (*g*) as w/w) and it is at zero weight of PVF resin, i.e. epoxy resin weight only is designated as standard ratio (0.00w/w) of prepared blend in the experiments.

Methodology

The nonreinforced and reinforced samples of the (epoxy-PVF) 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, Inc., 2007, USA). The bending distortion and bending deflection were determined using PHYWE instrument (three point bending tester). While the hardness property was determined using W Lestor Amsler, Harkeprufer, DIN 53505, ISO R868, Shore D). Mechanical properties of impact strength, bending distortion and hardness were performed according to ASTM D790 and their values measured directly by the instruments. On the other hand, the thermal conductivity test of prepared blend was achieved using Lee's disk instrument (Kocyigit Electronic, DC 0-30 volt, 6 Amperes; UK). The thermal conductivity property for the nonreinforced and reinforced samples at different weighted ratios of prepared blend 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 ($W/cm.^oC$)

Results and Discussion

A. Mechanical Tests

i. Hardness Test

Figure (1) shows the effect of nonreinforced samples at different weighted ratios of prepared blend on the shore hardness. It seems clearly that the values of hardness of nonreinforced samples increased from 65 to 82 *shore* with increasing the ratios of prepared blend from 0.00 to 0.21w/w and decreased to 80 shore at 0.26w/w. This behavior may be related to the increase in the ratios of prepared blend from standard ratio (0.00w/w) to 0.21w/w was associated with an increase in the weight of PVF resin from (0.0 to 0.4*g*) until to reach the strong chemical reaction and maximum bonding forces between two weights of epoxy and PVF resins at 0.21w/w. On the other hand, it can be clearly seen from figure (1) that the maximum hardness value of nonreinforced sample occurred at 0.21w/w that is designated as the optimum weighted ratio of prepared blend for hardness test.

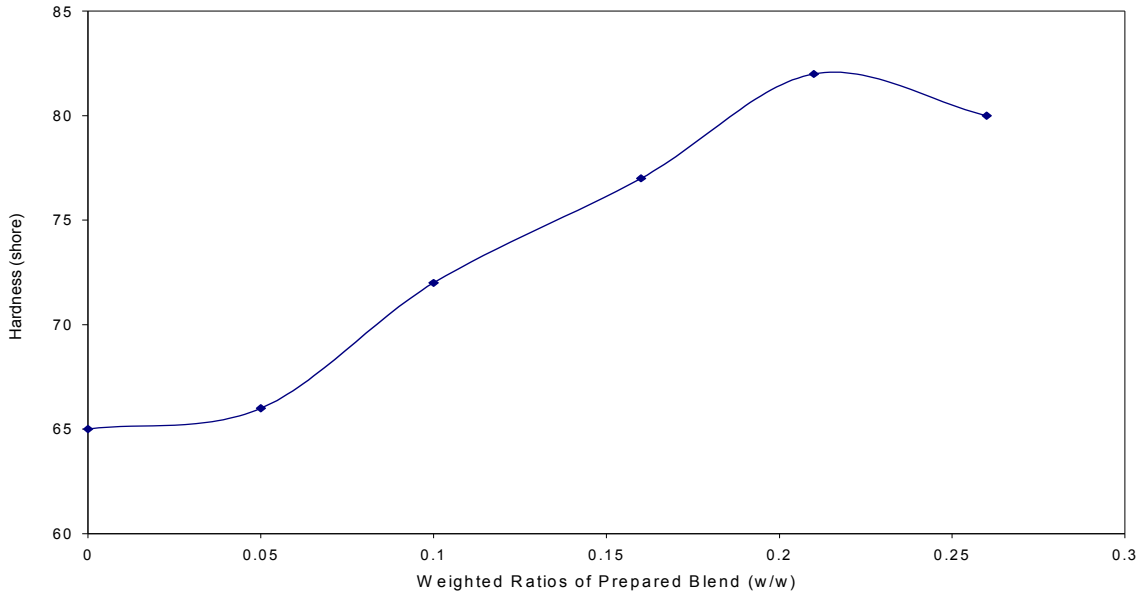

Figure 1: Effect of nonreinforced samples at different weighted ratios of prepared blend on the hardness property

Table (2) shows the effect of nonreinforced and reinforced samples with sacks and carbon fibers on the hardness property at standard and optimum weighted ratios of prepared blend. It is clear to see that the hardness values of the reinforced samples with sacks and carbon fibers in *shore* have higher values when compared to those of the nonreinforced samples. At the standard weighted ratio, the values of hardness for reinforced sample with sacks and carbon fibers increased by 15 and 8% respectively compared to that of nonreinforced sample. While at the optimum weighted ratio, they increased by 22 and 10% respectively.

Also, it clearly shows the hardness values of reinforced samples with sacks at standard and optimum weighted ratios have higher values when compared to those of reinforced

samples with carbon fibers. This can be related to the resistance of sacks that exhibited a better mechanical strength as reinforcing element to permanent deformation [1-2] and a strong fiber-matrix interfacial bond strength for giving high in hardness values [4-5].

Table 2: Effect of nonreinforced and reinforced samples on the hardness property at standard and optimum weighted ratios of prepared blend

Weighted Ratios of Prepared Blend (w/w)	Hardness in (*shore*)		
	Nonreinforced Samples	Reinforced Samples	
		Sacks	Carbon
Standard (0.00)	٦٥	75	70
Optimum (٠,٢١)	٨٢	١٠٠	٨٨

ii. Impact Strength Test

The effect of nonreinforced samples on the mechanical property, impact strength in J/cm^2 at different weighted ratios of prepared blend is shown in figure (2). It is clear to note that the weighted ratio of prepared blend at 0.10w/w showed a better chemical reaction and maximum bonding forces between the epoxide group of the epoxy and PVF group for the two resins because it gave the maximum impact strength (2.15 J/cm^2) compared to other ratios of prepared blend. The weighted ratio at 0.10w/w is designated as the optimum weighted ratio of prepared blend for impact strength test.

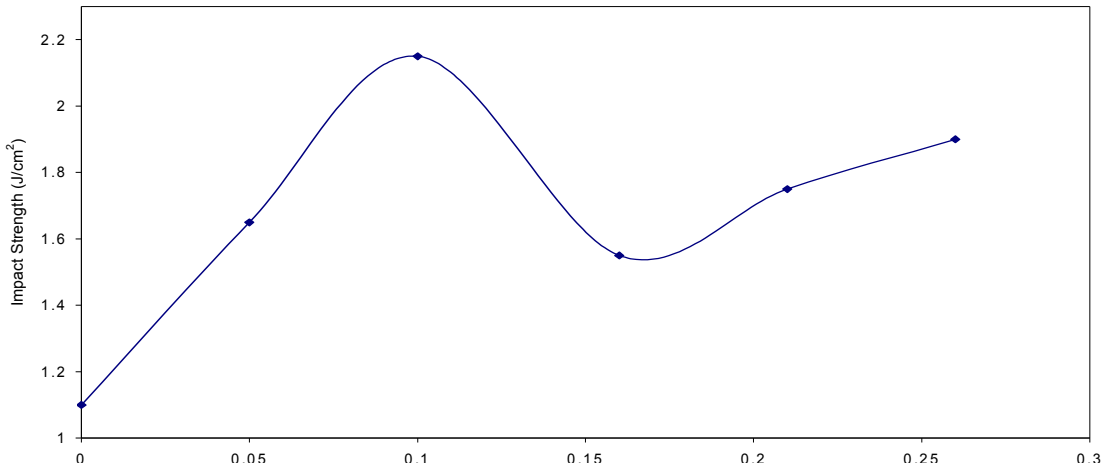

Figure 2: Effect of nonreinforced samples at different weighted ratios of prepared blend on the impact strength property

Table (3) shows the effect of nonreinforced and reinforced samples with sacks and carbon fibers on the impact strength property at the standard and optimum weighted ratios of prepared blend. It is clear to see that the impact strength values for reinforced samples with sacks and carbon fibers at standard weighted ratio have higher values and increased by 23 and 11% respectively compared to that of nonreinforced samples. On the other hand, for an optimum weighted ratio, they increased by 30 and 16% respectively.

On the whole, it is observed that the impact strength property of reinforced samples with sacks and carbon fibers at standard and optimum weighted ratios of prepared blend has been improved when compared to that of the nonreinforced sample. This can be attributed to the rigidity, interfacial stress resistance of sacks and carbon fibers that affected and improved significantly the impact resistance through the principle of stress transfer [6-7-8]. The sacks

effect on the impact strength property was predominant compared to the commercial carbon fibers. This effect depends on the strength, length and rigidity of sacks fibers [4-5].

Table 3: Effect of nonreinforced and reinforced samples on the impact strength property at standard and optimum weighted ratios of prepared blend

Weighted Ratios of Prepared Blend (w/w)	Impact Strength in (J/cm^2)		
	Nonreinforced Samples	Reinforced Samples	
		Sacks	Carbon
Standard (0.00)	1.10	1.35	1.22
Optimum (٠,١٠)	2.15	2.80	2.50

iii. Bending Test

(a) Bending Distortion

Figure (3) shows the effect of nonreinforced samples at different weighed ratios of prepared blend on the bending distortion in (*mm*), versus load in (*g*). It seems that the weighted ratio of prepared blend at 0.16w/w showed a better resistance and lower bending distortion values. The results provided evidence that the prepared blend at 0.16w/w reached to the optimum weighted ratio for bending distortion test.

As shown in figure (3), at any fixed weighted ratios, for example, 0.16 w/w, as the load values increase from (0 to 99.6 *g*), less resistance arises and higher bending distortion values. This trend is expected due to the change in the resistance of prepared blend against load values. Similar trends were obtained for other ratios (0.05, 0.10, 0.26w/w) of prepared blend.

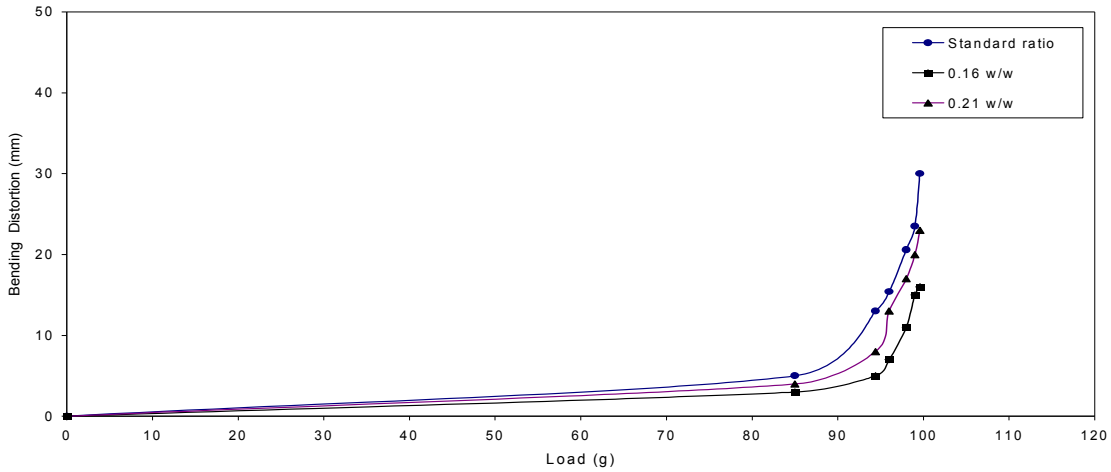

Figure 3: Effect of nonreinforced samples at different weighted ratios of prepared blend on the bending distortion property

Figures (4) and (5) show the effect of nonreinforced and reinforced samples with sacks and carbon fibers at standard and optimum weighted ratios of prepared blend in terms of bending distortion in (*mm*), versus load in (*g*). The bending distortion of nonreinforced sample has higher values when compared to the reinforced samples. On the other hand, bending distortion property is clearly improved for the reinforced samples with sacks and carbon fibers at standard and optimum weighted ratios of prepared blend due to the strong fiber-matrix interface bond that exhibited higher in bending distortion of composite [5].

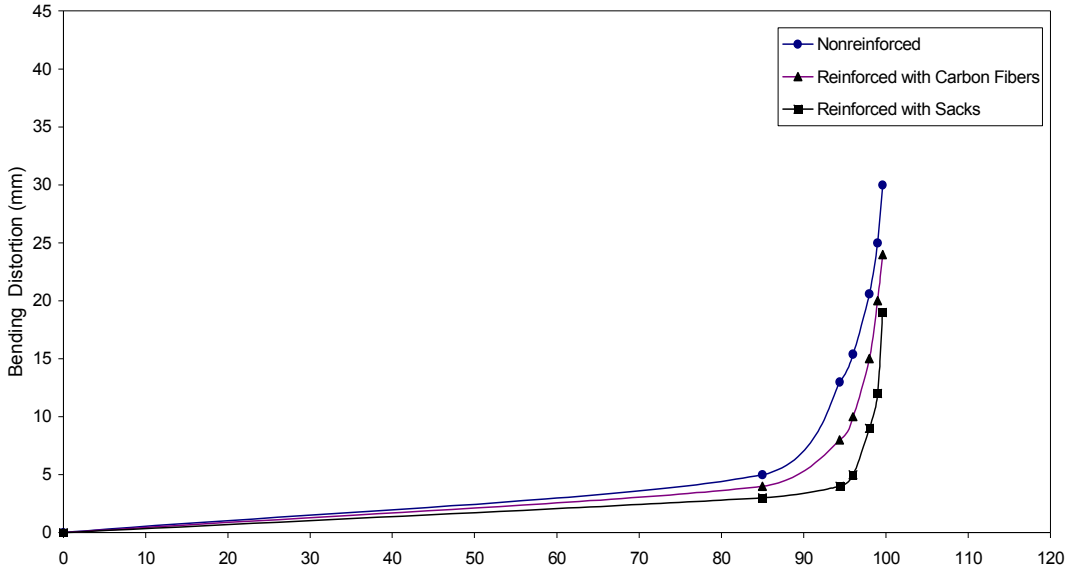

Figure 4: Effect of nonreinforced and reinforced samples on the bending distortion at standard weighted ratio of prepared blend

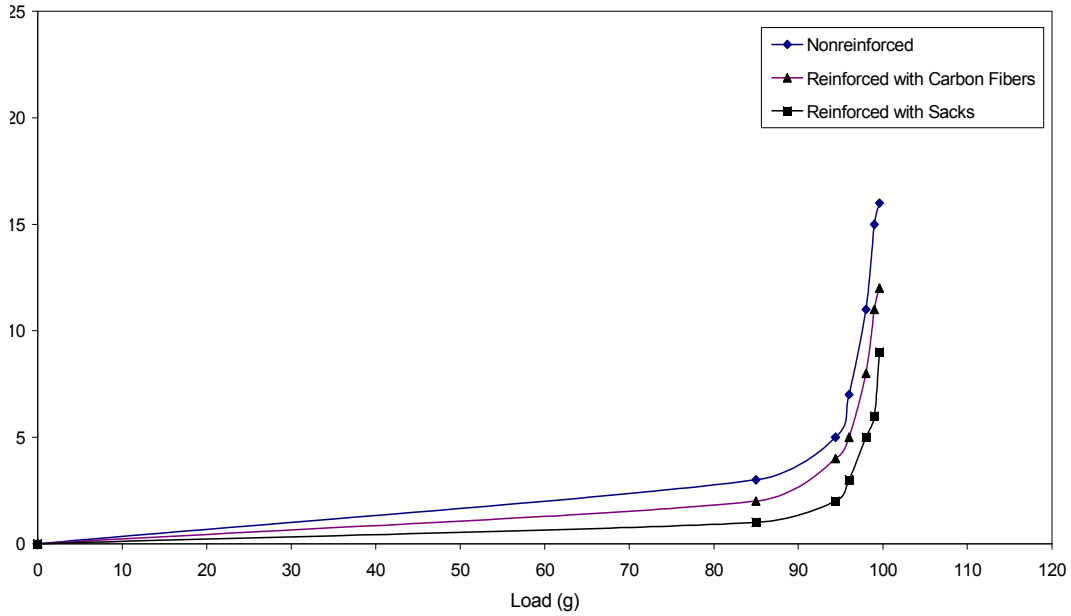

Figure 5: Effect of nonreinforced and reinforced samples on the bending distortion at optimum weighted ratio of prepared blend

Sacks composites at standard and optimum weighted ratios of prepared blend showed higher improvement in the bending distortion compared with the carbon fibers due to their strength, rigidity to help in supporting the structural load [4].

(b) Bending Deflection

The effect of nonreinforced samples on the bending deflection in *mm*, at different weighted ratios of prepared blend is shown in figure (6). It seems clearly that the values of bending deflection of nonreinforced sample decreased from 30 to 16*mm* with increasing the weighted ratios of prepared blend from standard ratio to 0.16w/w and increased to

27*mm* at 0.26w/w. It is seen from figure (6) that the minimum value of bending deflection of prepared blend occurred at 0.16w/w due to the excellent mechanical and chemical resistance of epoxy and PVF resins. It is designated as the optimum weighted ratio of prepared blend for the bending deflection test.

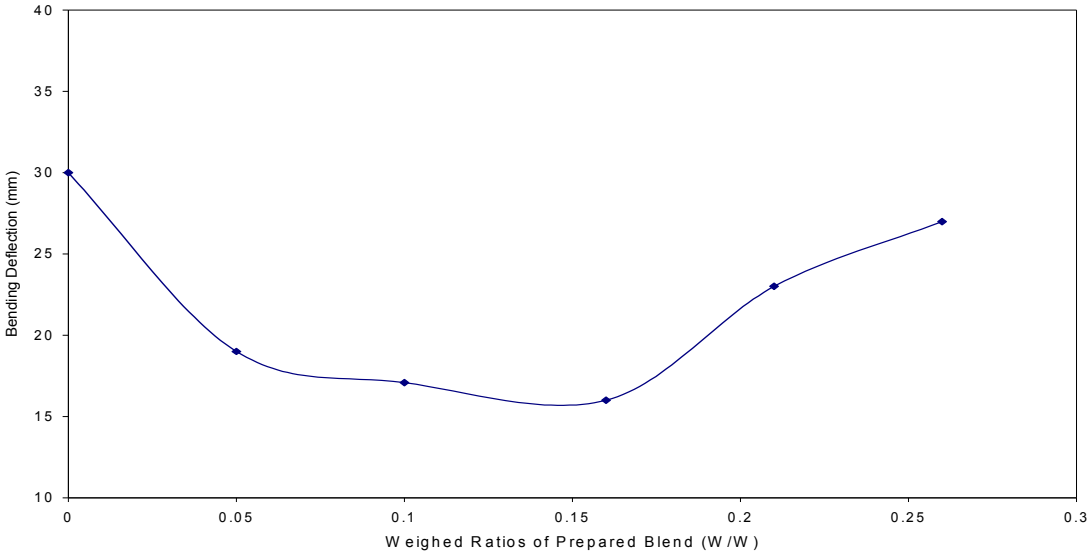

Figure 6: Effect of nonreinforced samples at different weighted ratios of prepared blend on the bending deflection property

Table (4) shows the effect of nonreinforced and reinforced samples with sacks and carbon fibers at standard and optimum weighted ratios of prepared blend on the bending deflection in *mm*. At standard weighted ratio, the values of bending deflection for reinforced samples with sacks and carbon fibers were improved by 58 and 25% respectively compared to that of nonreinforced sample. While at the optimum weighted ratio, they improved by 100 and 46% respectively. It was further noted that the reinforced samples with sacks lead to enhance the bending deflection property for both of standard and optimum weighted ratios of prepared blend and their effects were predominant due to their strength, rigidity in helping of structural load support [4].

Table 4: Effect of nonreinforced and reinforced samples on the bending deflection property at standard and optimum weighted ratios of prepared blend

Weighted Ratios of Prepared Blend (w/w)	Bending Deflection (*mm*)		
	Nonreinforced Samples	Reinforced Samples	
		Sacks	Carbon
Standard (0.00)	30	14	20
Optimum (٠,١٦)	16	8	12

B. Thermal Test

Figure (7) shows the effect of nonreinforced samples at different weighed ratios of prepared blend on the thermal conductivity property in $W/cm.^oC$. It seems clearly that the maximum value of the thermal conductivity of prepared blend occurred at standard ratio (0.00w/w). Also, it clearly shows the minimum value of the thermal conductivity of prepared blend correspond to 0.10w/w. On the other hand, the results provided evidence that the thermal conductivity of prepared blend at different weighted ratios is lower than that of its value at standard weighted ratio. This may be related to thermal resistance of PVF resin that led to

increase the over all thermal resistance of the (epoxy-PVF) blend and then decrease the thermal conductivity property of prepared blend. The prepared blend at the weighted ratio of 0.10w/w is designated as the optimum weighted ratio of prepared blend for thermal conductivity test.

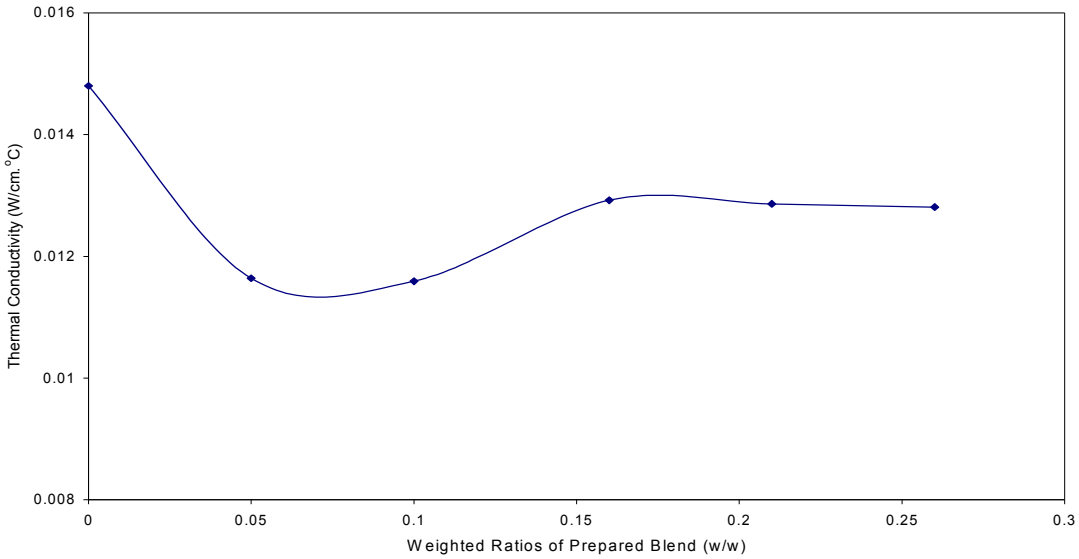

Figure 7: Effect of nonreinforced samples at different weighted ratios of prepared blend on the thermal conductivity property

The effect of nonreinforced and reinforced samples with sacks and carbon fibers on the thermal conductivity in *W/cm.°C* at standard and optimum weighted ratios of prepared blend is shown in table (5). It is clear to note that the thermal conductivity of reinforced samples with sacks and carbon fibers have lower values compared to those of the nonreinforced samples. At standard weighted ratio, the values of thermal conductivity of reinforced samples with sacks and carbon fibers improved by 16 and 6% respectively when compared to that of the nonreinforced samples. While at the optimum weighted ratio, they improved by 41 and 8% respectively.

It is generally observed that the sacks exhibited lower in thermal property values due to the best thermal resistance of them.

Table 5: Effect of nonreinforced and reinforced samples on the thermal conductivity property at standard and optimum weighted ratios of prepared blend

Weighted Ratios of Prepared Blend (w/w)	Thermal Conductivity (*W/cm.°C*)		
	Nonreinforced Samples	Reinforced Samples	
		Sacks	Carbon
Standard (0.00)	0.01480	0.0128	0.0139
Optimum (٠,1٠)	0.01159	0.0082	0.0107

Conclusions:

From the results presented, it can be concluded that

1. The reinforced samples with sacks and carbon fibers led to enhance and improve in the mechanical and thermal properties when compared to the nonreinforced samples.
2. The improvement of reinforced samples with sacks for mechanical and thermal properties is predominant compared to the carbon fibers and these improvements depend significantly on the fiber strength, fiber length and fiber – matrix interfacial bond strength.

3. Sacks may be recommended as favorable materials for making composites and environmentally friendly alternatives to conventional reinforcing fibers.

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