Polyester/Flax Biocomposites Reinforced Using Date Palm Leaves and Wood Flour As Fillers

Nermin M. Aly[*1] and D. E. El.Nashar [2]

[1] Spinning and Weaving Engineering Dept., Textile Research Division, National Research Centre, 33 El Bohouth st.(former El Tahrir st.),Dokki, Giza, Egypt,P.O.12622.

[2] Polymers and Pigment Dept., Chemical Industries Division, National Research Centre, 33 El Bohouth st.(former El Tahrir st.),Dokki, Giza, Egypt,P.O.12622.

* nermin_moh@yahoo.com

***Abstract* — Biocomposites based on natural fibers have exhibited several advantages like lightweight, high stiffness, biodegradability, low cost, which increased their usage as an effective alternative to synthetic fibers in various industrial applications. However, the awareness towards environmental issues leads to searching for new sources of natural fibers such as agricultural wastes. Date palm is one of the most economically implanted trees in Egypt and its by-products are widely used. As well, wood flour is a waste generated at different stages of wood processing industry. The study aimed to investigate the effect of using Date Palm Leaves (DPL) and Wood Flour (WF) as reinforcing fillers at (10, 20 and 30 wt.%) loading in polyester/flax woven sandwich biocomposites. Alkali treatment was applied to improve fibers/matrix adhesion and the fillers were characterized using FTIR spectroscopy. Mechanical properties such as the tensile strength, elongation at break and hardness, in addition to morphological analysis using SEM were studied. The results illustrated that, adding DPL and WF fillers to both types of polyester/flax biocomposites improved tensile strength and hardness but reduced elongation at break gradually. The highest tensile strength in warp direction was achieved with increasing fillers up to 20 wt.% ,while it was achieved at 10 wt.% in weft direction. Higher hardness values were obtained with warp rib 2/2 biocomposites using 20 wt.% DPL and at using 30 wt.% WF. Accordingly, the usage of DPL and WF as reinforcing fillers offered better enhancement in the mechanical performance of polyester/flax sandwich biocomposites.**

Keywords - Date palm leaves, Wood flour, Tensile strength, Hardness, Morphology analysis**.**

I. INTRODUCTION

The utilization of natural fibers as reinforcements or fillers in polymer matrices had attracted the attention in producing "Green" biocomposites in the last decades. This was driven by the environmental requirements and the need for recycling plastic materials. Biocomposites production is based on combining natural fibers with matrices from either renewable or non-renewable resources (petroleum based) [1]-[3]. Natural fibers have efficiently replaced synthetic fibers such as glass fibers to some extent in several applications since they offer various advantages like; renewability, non-toxicity ,biodegradability, low density, better thermal and acoustic insulating properties, low energy consumption during processing , low cost , reduced dermal and respiratory irritation , adequate strength and stiffness, etc.[4]-[8]. All of these advantages have broaden their usage in reinforcing composites for industrial applications, where providing sufficient rate of impact resistance, cracking control and ductile behaviour during break [6],[9]. The production of green composites had increased to 2.33 million tons in 2012 and it is predicted to reach 3.45 million tons by 2020 [10].

Natural fibers can be obtained from forestry and agricultural resources such as; flax, jute ,hemp, sisal, kenaf, wood, cotton, bagasse, rice straw, coir, oil palm, date palm, ramie, bamboo, etc [1],[5],[8]. Generally lignocellulosic fibers composed of major constituents like cellulose, hemicelluloses, lignin and non-structural substances such as; natural resins, essential oils, fats, wax, dyes, and proteins. The amorphous hemicelluloses and lignin work as cementing materials cross-linked to each other and act as a structural rigidity encapsulating the cellulose that crystallized and packed together [10],[11]. Agriculture wastes are used as fillers in polymeric matrices due to their ease of processing and low cost to produce alternative cheap eco-friendly materials for various fields. Date palm (*Phoenix dactylifera* L.) tree is one of the oldest plants belong to the family of Palmae (Arecaceae). It is the tallest *Phoenix* species, can be found with heights of more than 30 m and has fruit reaching up to (100×40 mm) in size [1],[8],[12]. Date palm has a significant role in the Egyptian agriculture, in addition to its nutritional and health benefits its by-products are daily used in industry. The trunk of date palm is surmounted by array of pinnate divided long leaves and fronds. Around (10-20) new leaves are produced annually, ranges in length from (40-70 cm). Large quantities of date palm rachis and leaves wastes accumulated every year after harvesting fruits without proper utilization. These wastes are estimated to be more than 20 kg

for each date palm tree, a small fraction of these leaves is used in construction but the bulk of it is wasted [8], [12]-[15].

The use of wood flour as fillers in producing Wood Plastic Composites (WPCs) is a cost-effective solution for the increasing costs of wooden products and construction materials. WPCs properties depend mostly on wood flour type, particle size, chemical treatment and matrix type [16]. Medupin, R.O. *et al* [17] had investigated the effects of using wood fiber with various loading on their composites properties for using in constructions, and it was found that increasing fiber loading improved the composites strength and stiffness but reduced their impact strength. Tshai K.Y. *et al.* [18] have studied the effect of varying empty fruit bunch palm fiber loading on their epoxy composites mechanical properties. It was revealed that, the tensile strength and flexural strength of the fiber loaded composites increased compared to neat epoxy one, while there was a reduction in the elongation at break. The use of natural fibers and wood fibers in producing lightweight composites is beneficial in structural applications for building such as fencing, decking, roofing and railing. Also, used in automotive applications due to weight reduction and fuel saving, including interior panels, headliners, dashboard, car roofs, seat panels, acoustic panels, etc [2],[9].

The functional properties of natural fibers reinforced composites are greatly influenced by the bonding strength between the fibers and the matrix. Weak interfacial bonding can lead to undesirable properties of the composites that limit their industrial usage. Natural fibers have some drawbacks like high moisture absorption due to their hydrophilic property, poor wettability and low durability. The insufficient adhesion between the natural fibers and the matrix is due to the differences in polarity, since lignocellulosic fibers show high polarity related to their chemical structure, while the matrices are nonpolar polymers such as polyethylene and polypropylene. Hence, the high hydroxyl group (-OH) content of cellulose makes it susceptible to absorb water and reacts to form hydrogen bonds that act as a separating agent in the fiber/matrix interface and leads to layers separation [5],[8],[10],[19]. To improve the adhesion between fibers and matrix, several methods could be applied either by modifying the surface of the fibers mechanically, chemically or physically to make them more compatible with the matrix and increasing their wettability, or by modifying the matrix with a coupling agent that adheres well to both fibers and matrix [9],[10]. Various chemical modification techniques have been used, such as alkaline treatment, acetylation, benzoylation, silylation, esterification, etc [20]. Farsi M. [21] used different chemical treatments to improve adhesion in the interface region and it was found that, the alkaline treatment improved the tensile strength. Alkali treatment of natural fibers, removes impurities covering the surface of fibers, increasing surface roughness, reduce fibers swelling, increasing the effective surface area for contact with the matrix and allows better fiber wetting, resulting in better mechanical interlocking [2],[8],[20], [22]. The effect of alkali treatment and acid treatment on date palm fibers was investigated and it was reported that, surface morphology and tensile strength of alkali treated fibers were improved compared to acid treated fibers that showed decline in their strength and morphology [8]. Also, Jamasri *et al.* [23] indicated that, the treatment with NaOH improved the tensile properties of oil palm fiber composites.

The aim of this work is to investigate the effect of using date palm leaves and wood flour as reinforcing fillers at different weight loading in polyester/flax woven sandwich biocomposites. Alkali treatment was applied to improve fibers/matrix interfacial adhesion. FTIR spectroscopy was used to characterize the alkali treated fillers. Mechanical properties of the proposed biocomposites such as tensile strength, elongation at break, hardness were examined and surface morphology was studied using SEM.

II. EXPERIMENTAL

A. Materials:

Polyester/Flax woven blended fabrics were manufactured using polyester fibers in warp yarns and flax fibers in weft yarns weaved with warp rib 2/2 and twill 2/2 structures. The physical properties of the woven fabrics are presented in Table 1. Date Palm Leaves (DPL) were collected from date palm trees in El-Maamoura Botanical Garden, Horticultural Institute, Alexandria. The leaves were extracted from the date palm fronds manually. The average length, width and thickness of leaves were 50.6 cm, 1.3 cm and 0.05cm, respectively. Wood Flour (WF) of pine wood (Local name: Mosky) was obtained from the sawmill wastes. Polyester resin was used as the matrix with the catalyst Methyl ethyl ketone peroxide and the accelerator Cobalt Napthanate. Sodium hydroxide was used for the alkali treatment of fabrics and fillers.

TABLE 1. Woven Fabric Properties.

Fabric materials	Weaving structure	Thickness (mm)	Weight (g/m^2)
Polyester/Flax (P/F)	Warp Rib 2/2	0.9	375
	Twill 2/2	0.93	377

B. Alkali Treatment:

The fillers and the fabrics were alkali treated to modify their surface before biocomposites preparation as follows:

- Date Palm Leaves (DPL) were washed with tap water to remove the contaminants and adhering dust before treatment, then were air-dried for 72 h, see figure 1.The DPL were immersed in a solution of 1% NaOH at room temperature for 12h and then the fibers were thoroughly washed with water, followed by neutralization with acetic acid. The treated DPL were rinsed with water and left to air drying for 72h. After that, the fibers were ground into particles using grinding machine.

- Wood Flour (WF) was immersed in a solution of 1% NaOH at room temperature for 4h, then were washed with tap water, neutralized with acetic acid, and washed several times then left to air drying for 72 h.

- Polyester/Flax (P/F) blended fabrics were alkali treated to remove the natural impurities found in flax fibers. The fabrics were emerged in a solution of 0.5% NaOH for 30 min. at 70°C. The fabric was washed thoroughly with water and then neutralized with acetic acid, followed by washing and air drying.

Fig.1. Date palm leaves after drying.

C. Sieving:

The treated DPL and WF were screened and sieved for size separation by using sieve meshes from no.18-70 to eliminate big and fine fibers. The fibers used in the study are that retained on sieve (mesh 70) of average size 210 μm and length of (1-3mm). Figure 2 shows treated DPL and WF fibers after sieving.

Fig.2. Treated fibers; (a) date palm leaves and (b) wood flour after sieving.

D. Biocomposites Preparation:

The study aimed to investigate the effect of using DPL and WF as reinforcing fillers at (10, 20 and 30 wt.%) loading in polyester/flax biocomposites. So in this regard, the composites were prepared using the hand lay up technique in the form of a sandwich structure with skins from woven fabric and the filler core layer. Firstly, the mold was prepared using mold releasing agent applied on its surface. Polyester resin, hardener and catalyst were mixed to form the matrix according to the mixing ratios, then the fabrics were impregnated with the resin. Each type of the filler was used separately with the specified weight content, poured gradually and stirred within the matrix to make a homogeneous mixture. The filler/resin mixture is added in-between the skin layers until there is proper wetting. The biocomposites specimens were left to cure at room temperature for 48h before it is removed. The specifications of the sandwich composites produced are presented in Table 2.

TABLE 2. Polyester/flax Sandwich Biocomposites Specifications.

Sample no	Sandwich composites	Filler (%)	Skin weaving structure
1	P/F	-	Warp rib 2/2
2	P/F	-	Twill 2/2
3	P/F/DPL	10	Warp rib 2/2
4	P/F/DPL	10	Twill 2/2
5	P/F/DPL	20	Warp rib 2/2
6	P/F/DPL	20	Twill 2/2
7	P/F/DPL	30	Warp rib 2/2
8	P/F/DPL	30	Twill 2/2
9	P/F/WF	10	Warp rib 2/2
10	P/F/WF	10	Twill 2/2
11	P/F/WF	20	Warp rib 2/2
12	P/F/WF	20	Twill 2/2
13	P/F/WF	30	Warp rib 2/2
14	P/F/WF	30	Twill 2/2

E. Testing:

1) Fourier Transform Infrared (FTIR) Spectroscopy:

FTIR spectra of treated and untreated filler samples were measured using ATR technique based on FTIR spectrometer (VERTEX 70, Bruker Optics),Germany. The spectral range 4000-400 cm^{-1} was recorded .The obtained data was analyzed using OPUS software (Bruker Optics). The test was performed at the Spectroscopy department, National Research Centre.

2) Tensile Strength Test:

The tensile strength test of the sandwich biocomposites specimens was carried out according to ASTM D638, using an electronic Zwick tensile testing machine, model 1425, Germany. The tests were performed at a cross-head speed of 100 mm/min. Tensile strength and elongation at break were determined in both the warp and weft direction of fabrics. The test was performed at the Polymers and pigment department, National Research Centre.

3) Hardness Test:

Shore-D hardness value of the sandwich biocomposites specimens was determined according to ASTM D2240, using Braive instruments hardness tester .The test based on the penetration of the Durometer indentor when forced into the material. Subsequent readings at different points were taken after the indenter made contact with the specimen. The test was carried out in the Material testing laboratory, National Research Centre.

4) Morphological Analysis:

Surface morphology of the sandwich biocomposites was examined using Scanning Electron Microscope (SEM), Model Philips XL 30, Netherlands. The fractured surfaces of the specimens were coated with gold prior to the morphological observation. SEM micrographs of the specimens were used to study the fillers distribution in the composites structure and the fiber/matrix interfacial bonding. The test was carried out in the Central laboratories sector at the Egyptian Mineral Resources Authority.

III. RESULTS AND DISCUSSION

The untreated and alkali treated fillers was analyzed and characterized using Fourier Transform Infrared (FTIR) Spectroscopy. The effect of using DPL and WF as reinforcing fillers at different weight loading in polyester/flax sandwich biocomposites on their mechanical properties was studied and illustrated as follows:

A. FTIR Spectroscopic Analysis:

The fillers were alkali treated to remove hemicelluloses and lignin from the fibers surface. The efficiency of treatment on fillers was analyzed according to the basis of the assignments in literature [24],[25]. Figure 3 shows the FTIR spectra of untreated and treated DPL. Figure 4 shows the FTIR spectra of untreated and treated WF. It can be observed from figure 3 that, the absorption bands found at 2915 cm^{-1} and 2848 cm^{-1} are attributed to the C-H group stretching vibration in methyl and methylene groups in cellulose and hemicelluloses, which increased due to the removal of hemicelluloses. The peak at 1710 cm^{-1} is assigned to the C=O group stretching

in carbonyl groups of lignin and hemicelluloses, and a new peak appeared. The absorption bands at 1472 cm^{-1} and 1463 cm^{-1} corresponds to the bending deformation of CH_2 groups of lignin. The peak at 1310 cm^{-1} is assigned to the C-H group bending in cellulose and hemicelluloses, and the sharp peaks appeared at 730 cm^{-1} and 719 cm^{-1} are attributed to the rocking vibrations of -CH_2 group in lignin.

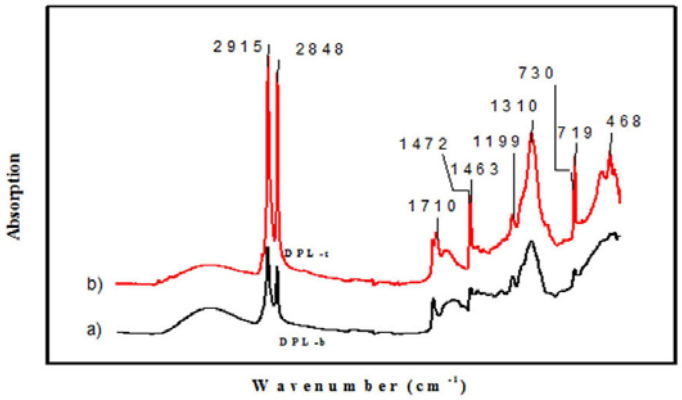

Fig.3. FTIR spectra of; (a) untreated and (b) treated date palm leaves.

Also from figure 4, it can be observed that the absorption band at 3336 cm^{-1} is assigned to the stretching vibration of hydroxyl group -OH, which are found in cellulose, lignin and hemicelluloses in fibers. The peak at 2892 cm^{-1} is assigned to the C-H stretching vibration in the methyl and methylene groups and its intensity decreased after treatment due to the removal of hemicelluloses. The absorption bands at 1596 cm^{-1} and 1507 cm^{-1} are attributed to the stretching vibration of C=C group in the aromatic rings of lignin . The peak at 1262 cm^{-1} is assigned to the C=O stretching of acetyl group of lignin and it is reduced because of the partial removal of lignin from the surface of fibres. The peak at 1026 cm^{-1} is assigned to the C-O group stretching in cellulose and the C-O deformation in lignin.

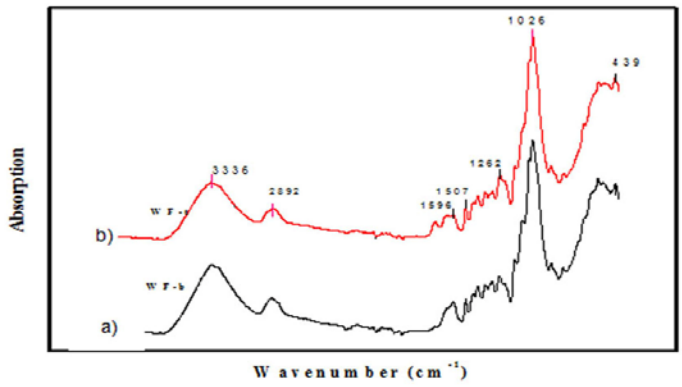

Fig.4. FTIR spectra of; (a) untreated and (b) treated wood flour.

B. Tensile Strength Test:

The tensile test has been carried out with respect to the warp and weft directions of skin fabrics in the sandwich biocomposites specimens. Figure 5 shows the effect of fillers loading on the tensile strength of the biocomposites in warp direction. It was indicated that, the unfilled P/F warp rib 2/2 biocomposites showed higher tensile strength values than P/F twill 2/2 biocomposites. This could be related to the rib structure that has more intersections compared to twill structure, leading to increasing the contact friction area between yarns, reducing their capability to slippage and providing more resistance to the tensile load. Adding reinforcing fillers to P/F biocomposites showed an improvement in their strength. The tensile strength increased as DPL filler content increased up to 20 wt.% and decreased at 30 wt.% for warp rib 2/2 composites ,and it increased up to 30 wt.% for twill 2/2 composites. Where adding 10% DPL increased tensile strength by 21% and 26.4% for warp rib 2/2 and twill 2/2 biocomposites, respectively. Adding 20% content increased tensile strength to 62.4% and 33.3% for warp rib 2/2 and twill 2/2 biocomposites, respectively and when 30% content is added, the tensile strength increased by 41% for twill 2/2 biocomposites.

On the other hand, the tensile strength increased as WF filler content increased up to 30 wt.% for warp rib 2/2 biocomposites , and it increased at using WF up to 20 wt.% and decreased at 30 wt.% for twill 2/2 biocomposites. At adding 10% WF, the tensile strength increased by 6% and 24.6% for warp rib 2/2 and twill 2/2 biocomposites, respectively. Also, adding 20% content increased tensile strength by 20% and 57.8% for warp rib 2/2 and twill 2/2 biocomposites, respectively. While at adding 30% content, the tensile strength increased by 49% for warp rib 2/2 biocomposites. The improvement in tensile strength is due to the properties of the skin fabrics materials and the good dispersion of filler in the matrix, leading to good interfacial bonding between fibers and matrix which increased the load bearing capability of P/F biocomposites. Although the reduction in tensile strength at 30% filler loading may be related to the poor adhesion and weak fibers/matrix interaction bonding due to the agglomeration of filler particles that affected on the stress transfer between the fibers. In addition to the lack of free spaces for yarns to move during exposure to load, so it exhibited less resistance. Also it was observed that, the P/F/DPL sandwich biocomposites showed better tensile strength compared with P/F/WF sandwich biocomposites, due to the good bonding between DPL filler and polyester matrix.

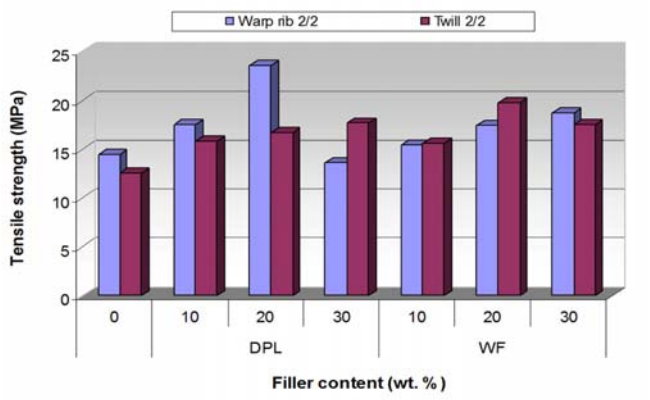

Fig.5. Effect of filler content on the tensile strength of polyester/flax sandwich biocomposites in the warp direction.

Figure 6 shows the effect of fillers loading on the tensile strength of the sandwich biocomposites in weft direction. It was indicated that, the tensile strength in weft direction of polyester/flax biocomposites is higher than that in warp direction, as a result of increasing number of yarns intersections that makes yarns crimp, increasing their resistance to extend and stand the load. The unfilled warp rib 2/2 biocomposites showed higher tensile strength than twill 2/2 biocomposites. Adding 10% filler content enhanced the tensile strength of P/F sandwich biocomposites. It increased by 13% and 8% for warp rib 2/2 and twill 2/2 biocomposites produced using DPL, respectively. Also it increased by 20% and 24% for warp rib 2/2 and twill 2/2 biocomposites produced using WF, respectively. This may be related to good wetting with polyester resin that increased fibers/matrix interface surface area, leading to better bonding between them. As both fillers content increased from (20-30 wt.%), the tensile strength decreased gradually, because the P/F biocomposites reached their maximum strength at 10 wt.% and beyond this with increasing filler content ,the interfacial area decreased resulting in agglomeration of fillers which obstructs the polymer chain movement, weakens the fibers/matrix interactions so the stress will not be able to spread between fibers evenly to withstand load.

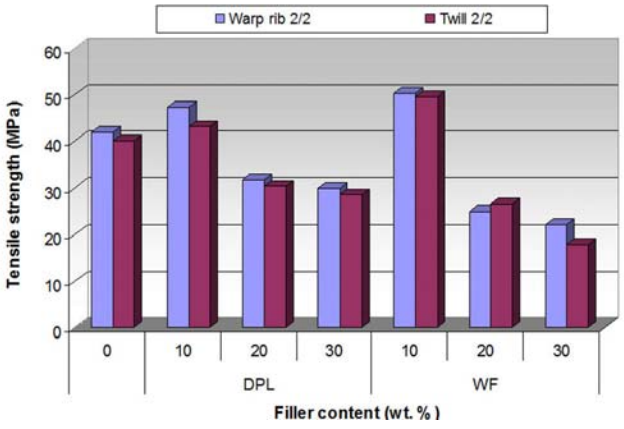

Fig.6. Effect of filler content on the tensile strength of polyester/flax sandwich biocomposites in the weft direction.

C. Elongation at Break Test:

Figure 7 shows the effect of fillers loading on the elongation at break of polyester/flax sandwich biocomposites in warp direction. It was indicated that, the unfilled biocomposites showed higher elongation values compared with the filled biocomposites. The unfilled twill 2/2 composites showed higher elongation owing to the presence of more floats in the twill structure of the skins. The increase in both fillers content from (10-30 wt.%) decreased the elongation at break for both warp rib 2/2 and twill 2/2 biocomposites gradually. The increase in filler content leads to more stiffness of the composites and reducing their ductility which led to lower elongation at break. Also, filler agglomeration leads to poor adhesion between fibers and matrix and form stress concentration areas that cannot be able to resist crack propagation.

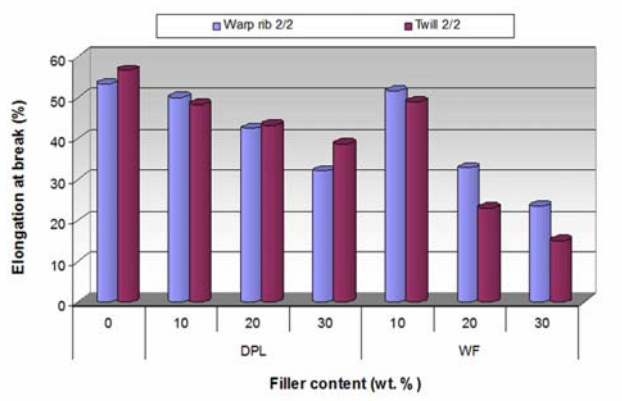

Fig.7. Effect of filler content on the elongation at break of polyester/flax sandwich biocomposites in the warp direction.

Figure 8 shows the effect of fillers loading on the elongation at break of polyester/flax sandwich biocomposites in weft direction. It was observed that, the elongation at break of P/F biocomposites in weft direction showed higher values compared to that in warp direction. This could be related to that, the warp and weft yarns interlaced during weaving and crimped so when exposed to stress, the crimps opens allowing yarns to elongate. The unfilled warp rib 2/2 biocomposites showed higher elongation values compared with twill 2/2 biocomposites. The increase in both fillers content from (10-30 wt.%) decreased the elongation at break for both warp rib 2/2 and twill 2/2 biocomposites produced using DPL and also for twill 2/2 biocomposites produced using WF. Due to the inability of the filler to support the stress transfer from fibers to matrix leading to brittle behaviour of composites that reduces its elongation. On the other hand, it increased at 30% wt. content for warp rib 2/2 composites produced using WF filler. Also it was observed that, the P/F sandwich composites produced using DPL filler showed better elongation at break compared with those produced using WF filler due to better fibers interactions and adhesion with polyester matrix.

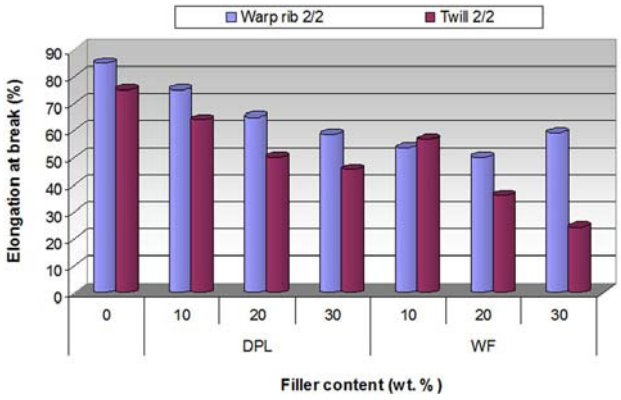

Fig.8. Effect of filler content on the elongation at break of polyester/flax sandwich biocomposites in the weft direction.

D. Hardness Test:

Figure 9 shows the effect of fillers loading on the hardness of polyester/flax sandwich biocomposites. It was indicated that, the unfilled warp rib 2/2 biocomposites showed high hardness values compared to twill 2/2 biocomposites. Also, there is an enhancement in the sandwich biocomposites hardness with increasing both

fillers content. Warp rib 2/2 biocomposites produced using 20 wt.% DPL content achieved the highest hardness value as it increased by 4%. While the twill 2/2 biocomposites has no remarkable changes when DPL content increased from (10-20%) and it achieved its highest hardness value with 10 wt.% content as it increased by 2%, owing to the good fiber/matrix interactions and good impregnation with the resin. When DPL content increased up to 30 wt.%, there is reduction in the hardness values for both warp rib 2/2 and twill 2/2 biocomposites due to poor filler distribution and weak bonding with the matrix. On the other hand, warp rib 2/2 biocomposites produced using 30% WF content achieved the highest hardness as it increased by 6%. While the twill 2/2 biocomposites achieved its highest value with 20% WF content as it increased by 4%. Then, there is reduction in hardness value at 30% content due to the poor surface adhesion of the filler with polyester matrix. Also it was indicated that, the P/F/WF biocomposites achieved better hardness values compared to P/F/DPL biocomposites.

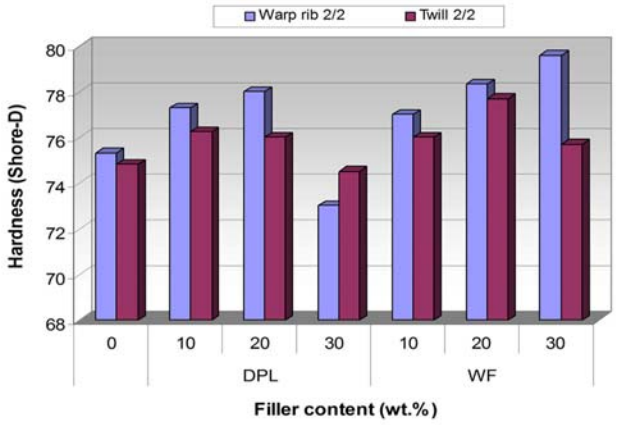

Fig.9. Effect of filler content on the hardness of polyester/flax sandwich biocomposites.

3.5. Morphological Analysis:

Figures (10-14) show SEM micrographs of the fractured surfaces of polyester/flax sandwich biocomposites produced unfilled and filled with DPL and WF at 10% and 20% wt. content. Fiber/matrix adhesion and the dispersion of the fillers in the matrix had great influences on enhancing the mechanical properties of P/F biocomposites. Morphology of the fractured surface of specimens indicated good interactions between fibers and matrix. In figure 10(a&b), the unfilled warp rib 2/2 and twill 2/2 biocomposites were well impregnated with polyester resin on their surface due to better fiber/matrix interface interactions. It was observed from figure 10(b) that, the twill 2/2 composites are more covered with polyester resin, due to the presence of floats in the twill structure that facilitates more penetration of resin. Fibers pull-out and matrix cracks appeared as a result of stress transfer during exposure to loads. Figures (11&12) show the fractured surfaces of the two types of P/F biocomposites produced using 10 wt.% content of DPL and WF fillers. It was clear the dispersion of fillers within the matrix, however there is agglomeration of filler in some places. Fiber/matrix debonding is shown due to weak adhesion between the pulled-out fibers and the matrix during exposure to loads. Figures 13&14 show the fractured surface of P/F biocomposites produced using 20% DPL and WF fillers, respectively. It was evident that, at 20% filler content, there is more dispersion of the fillers in the matrix, leading to increasing the interface surface area and good fiber/matrix bonding to support stress transfer and distribute it in the biocomposites leading to a higher tensile strength. There is a better adhesion of DPL filler with the skin fibers and the matrix compared to WF filler. Although some agglomerated areas are formed which weaken the fibers/matrix adhesion. Fibers pull-out and fiber/matrix debonding is cleared in the fractured surface especially with twill 2/2 biocomposites.

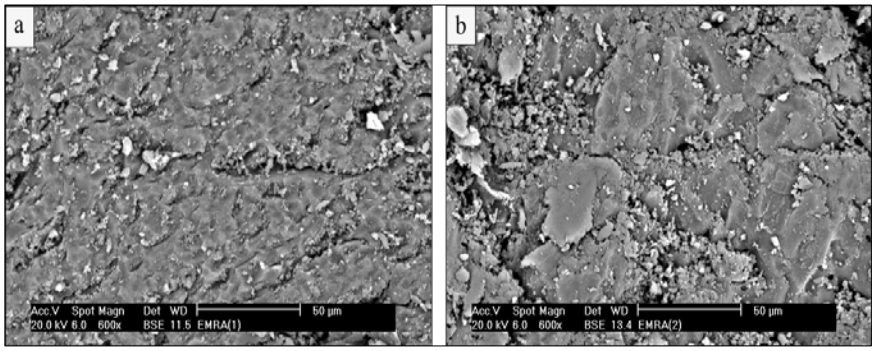

Fig.10. SEM of the unfilled polyester/flax sandwich biocomposites;
(a) warp rib 2/2 and (b) twill 2/2.

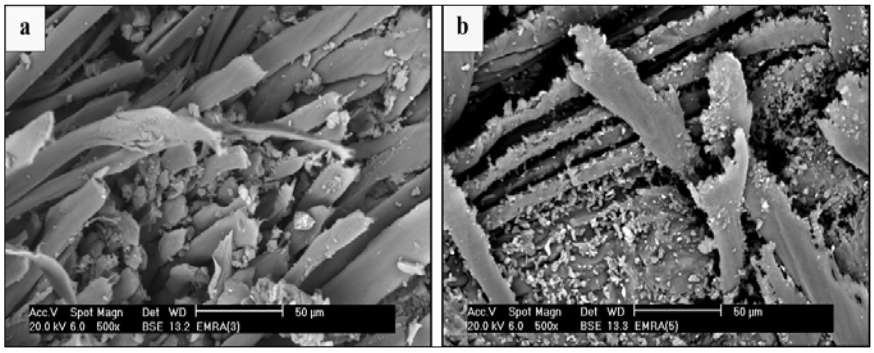

Fig.11. SEM of warp rib 2/2 polyester/flax sandwich biocomposites at; (a) 10% DPL content and (b) 10% WF content.

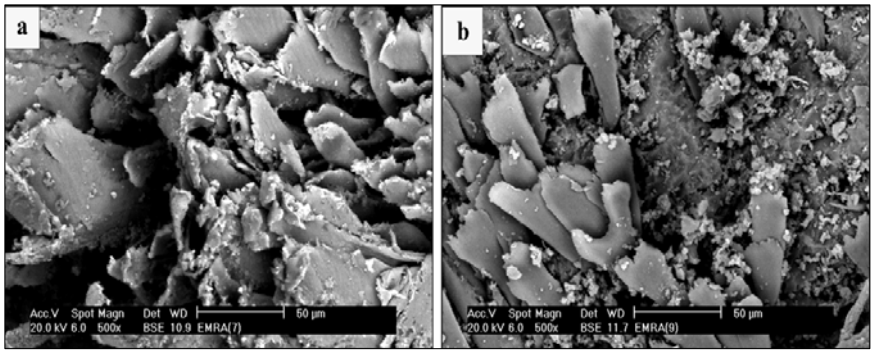

Fig.12. SEM of twill 2/2 polyester/flax sandwich biocomposites at; (a) 10% DPL content and (b) 10% WF content.

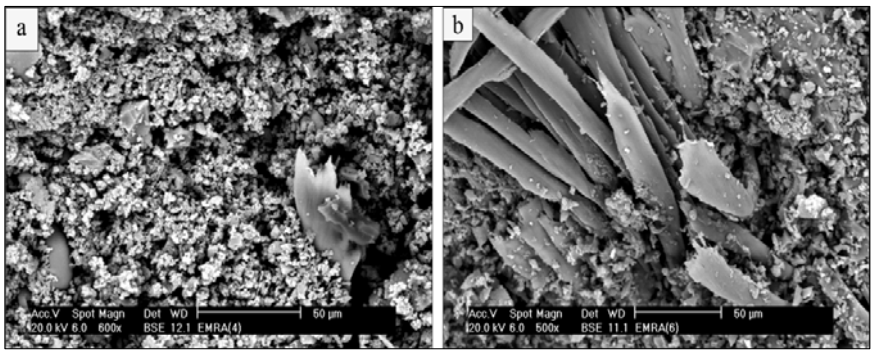

Fig.13.SEM of warp rib 2/2 polyester/flax sandwich biocomposites at; (a) 20% DPL content and (b) 20% WF content.

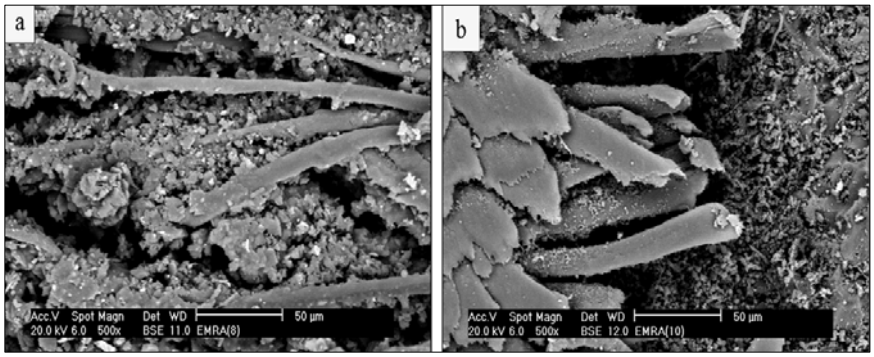

Fig.14. SEM of twill 2/2 polyester/flax sandwich biocomposites at; (a) 20% DPL content and (b) 20% WF content.

IV. CONCLUSION

Agriculture wastes such as date palm leaves and wood flour were used as reinforcing fillers at (10, 20 and 30 wt.%) loading in polyester/flax woven sandwich biocomposites. Polyester/flax fabrics were produced using warp rib 2/2 and twill 2/2 weaving structures. The effect of fillers content on the tensile strength, elongation at break and hardness was investigated. It was found that, the P/F biocomposites properties were greatly affected by the fillers weight content. Adding fillers to the biocomposites improved their tensile strength in the warp direction and in the weft direction to certain extent. The highest tensile strength was found at using 20 wt%. fillers loading in the warp direction, while it was achieved at 10 wt.% fillers loading in the weft direction. Higher hardness values were obtained with warp rib 2/2 composites using 20 wt.% DPL filler and at using 30 wt.% WF filler. While elongation at break was reduced gradually with increasing fillers loading. Also it was indicated that, warp rib 2/2 sandwich biocomposites produced using DPL and WF fillers showed better improvement in their mechanical performance compared with twill 2/2 biocomposites. So developing new biocomposites using agricultural wastes is a promising solution for plastic recycling from environmental and economical aspects.

REFERENCES

[1] G.A. Bibo, P.J. Hogg and M. Kemp, "Mechanical Characterization of Glass and Carbon Fiber Reinforced Composites Made with Non-crimp Fabrics", Compos Sci Technol., vol. 57(9-10), pp.1221-1241, 1997.

[2] M.Farsi, Thermoplastic Matrix Reinforced with Natural Fibers: A Study on Interfacial Behaviour, In: Wang J (Ed.) Some Critical Issues for Injection Molding, Intech, Rijeka, Pp.225-250, 2012.

[3] R. Agarwal, M. Ramachandran and S.J.Ratnam, "Tensile Properties of Reinforced Plastic Material Composites with Natural Fiber and Filler Material", ARPN J Eng Appl Sci., vol.10(5),pp.2217-2220, 2015.

[4] S.N. Rafeeq, I.M. Abdulmajeed and A.R. Saeed, "Mechanical and Thermal Properties of Date Palm Fiber and Coconut Shell Particulate Filler Reinforced Epoxy Composite", Indian J Appl Res., vol. **3**(4),pp.89-92, 2013.

[5] C.W. Nguong, S.N.B. Lee and D.Sujan ,"A Review On Natural Fiber Reinforced Polymer Composites", Int J Chem, Mol, Nucl, Mater Metall Eng, vol. **7**(1),pp.33-40,2013.

[6] A.O. Ameh, M.T. Isa and I.Sanusi, "Effect of Particle Size and Concentration on the Mechanical Properties of Polyester/Date Palm Seed Particulate Composites", Leonardo El J Pract Technol., Issue 26,pp.65-78, 2015.

[7] M. Jawaid, H.P.S. Abdul Khalil, A. Hassan, et al., "Effect Of Jute Fiber Loading on Tensile and Dynamic Mechanical Properties of Oil Palm Epoxy Composites", Compos Eng., vol.45(1), pp. 619-624, 2013.

[8] F.M. Al-Oqla, O.Y. Alothman, M. Jawaid, et al., Processing and Properties of Date Palm Fibers and Its Composites, In: Hakeem KR, Jawaid M and Rashid U (Eds) Biomass and Bioenergy, Processing and Properties, Chapter 1, Springer, International Publishing AG, Switzerland, Champp,1-25, 2014.

[9] M. Asadzadeh, S.M.R Khalili, R. EslamiFarsani, et al., " Bending Properties Of Date Palm Fiber And Jute Fiber Reinforced Polymeric Composite", Int J Adv Des Manuf Tech., vol.5(4),pp.59-63, 2012.

[10] D. Paukszta and S. Borysiak, "The Influence of Processing and the Polymorphism of Lignocellulosic Fillers on the Structure and Properties of Composite Materials-A Review", Materials , vol. 6(7),pp.2747-2767, 2013.

[11] N.F. Jasmi, J. Kasim, N.F.Yusoff, et al.,"Effect of Alkali Treatment on Mechanical and Physical Properties of Oil Palm Frond-Polypropylene Matrix", Int J Lat Res Sci Tech., vol. 3(6),pp.150-154, 2014.

[12] K. Al-Kaabi, A. Al-Khanbashi and A..Hammami, "Date Palm Fibers As Polymeric Matrix Reinforcement: DPF/Polyester Composite Properties", Polym Compos., vol. 26,pp.604-613, 2005.

[13] H. Hosseinkhani, M. Euring and A.Kharazipour, "Utilization of Date Palm (Phoenix Dactylifera L.) Pruning Residues as Raw Material for MDF Manufacturing", J Mater Sci Res., vol. 4(1),pp.46-62, 2015.

[14] S. Bekheet, "Date Palm Biotechnology in Egypt (Review Article)", Appl Sci Rep., vol. 3(3),pp.144-152, 2013.

[15] F. Al-Sulaiman , "Mechanical Properties of Date Palm Leaves", J Reinf Plast Comp.,vol.19(17),pp.1379-1388, 2000.

[16] N.L. Bhandari, S.Thomas, C.K. Das, et al., "Role Of Compatibilizer on Morphological and Mechanical Properties of Low Cost Polypropylene/Wood Flour Composites", J Nepal Chem Soc., vol. 29,pp.113-120, 2012.

[17] R.O. Medupin and O.K. Abubakre, " Effect of Wood Fibre Characteristics on the Properties of Wood Polymer Composites, J Multi Eng Sci Tech.,vol 2(1),pp.101-105, 2015.

[18] K.Y. Tshai, E.H. Yap and T.L.Wong, "The Effects of Weight Fraction on Mechanical Behaviour of Thermoset Palm EFB Composite", Int J Mater, Mech Manuf., vol. 4(4), PP.232-236, 2016.

[19] P.Wambua, J. Ivens and I.Verpoest, "Natural Fibers: Can They Replace Glass In Fiber Reinforced Plastics?", Compos Sci Technol. ,vol. 63(9),pp.1259-1264, 2003.

[20] H. Kallakas, M.A. Shamim, T. Olutubo, et al., "Effect of Chemical Modification of Wood Flour on the Mechanical Properties of Wood-Plastic Composites", Agron Res.,vol. 13(3),pp.639-653, 2015.

[21] M. Farsi, " Wood-Plastic Composites: Influence of Wood Flour Chemical Modification on the Mechanical Performance", J Reinf Plast Comp., vol. 29(24),pp. 3587-3592, 2010.

[22] S. Kokot and S.Stewart, "An Exploratory Study of Mercerized Cotton Fabrics By Drift Spectroscopy and Chemometrics", Text Res J.,vol. 65(11),pp.643-651,1995.

[23] D.K. Jamasri and G.W. Handiko, "The Study of Alkali Treatment and Core Thickness to Bending Properties of the Sandwich Composite Reinforced Palm Fiber with Palm Wood Core", Ind J Mat Sci. , vol.8(1),pp.76-82, 2006.

[24] X. Colom, F. Carrillo, F. Nogues,et al., "Structural Analysis of Photodegraded Wood By Means of FTIR Spectroscopy", Polym Degrad Stab, vol.80(3),pp. 543-549, 2003.

[25] K.K. Pandey, "A Study of Chemical Structure of Soft and Hardwood and Wood Polymers by FTIR Spectroscopy", J App Polym Sci, vol. 71(12), pp.1969-1975,1999.