

Mechanical and Morphological Properties of Kenaf Cellulose/LDPE Biocomposites

¹Behjat Tajeddin, ²Russly Abdul Rahman and ³Luqman Chuah Abdulah

¹Department of Food Engineering and Post Harvest Technology,
Iranian Agricultural Engineering Research Institute (IAERI), P.O. Box 31585-845, Karaj, Iran

²Department of Process and Food Engineering, Faculty of Engineering,
UPM, 43400 Serdang, Selangor, Malaysia

³Laboratory Biopolymer and Derivatives,
Institute of Tropical Forestry and Forest Products (INTROP), UPM, 43400 Serdang, Selangor, Malaysia

Abstract: The possibility of using cellulose from the cell walls of kenaf, an annual herbaceous crop, for the production of biocomposites was investigated in this study. The composites were prepared using LDPE, as a matrix, the extracted cellulose, as filler and PEG as a plasticizer. The characterization of biocomposites was then performed with optimized thermo-mechanical properties and propensity to environmental degradation. This paper focuses only on the mechanical properties including tensile strength, flexural and Izod impact tests. The results showed that the mechanical properties of the composites was decreased slightly as the cellulose content increased from 0 to 50 wt % in the biocomposite formulation. It is interesting to note that in all treatments, the mechanical behavior of biocomposites retained in an acceptable level of strength. These findings were confirmed by the SEM study. Consequently, the suitable biocomposite material for food packaging was successfully obtained.

Abbreviations: LDPE, Low density polyethylene; UPM, University Putra Malaysia; SEM, scanning electron microscopy; PEG, polyethylene glycol; PE, polyethylene; PP, Polypropylene; Ts, tensile strength; Is, impact strength; Fs, flexural strength; OH, hydroxyl

Key words: Kenaf cellulose • LDPE • Tensile strength • Flexural strength • Impact strength • SEM

INTRODUCTION

The most important function of a packaging material is the preservation of the packed goods quality for storage, transportation and end-use. The quality of package depends on its materials [1]. Plastic materials (polymers) are one of the most important materials that are used in food packaging due to their advantages that are reflected in their physical, mechanical and chemical properties. They are stable in ambient and many hostile environments and not subject to degradation in normal use [2]. Among plastics, PE is the most widely used mass-produced plastic especially in food packaging. It is one of the usual synthetic polymers with high hydrophobic level and high molecular weight. In natural form, it is not biodegradable. Thus, their use in the

production of disposal or packing materials causes many problems [3]. The main problem is environmental pollution and solid waste management. Latest and harder ecological policies compulsives industries like packaging to look for new materials [4].

According to numerous excellent review papers by Weber [5], biobased food packaging materials can be used for food applications. However, biocomposites including biofibers (natural fibers) and matrix polymers like PE are an opportunity for overcoming the environmental problems. LDPE, a type of thermoplastic polymer with $-(CH_2-CH_2)_n-$ structure, is used as packaging material in the pharmaceutical and cosmetic industries as well as foods, toys and cleaning agents [2, 6]. LDPE has a highly branched chain that makes it a flexible, stretchable material [7].

From natural fibers, kenaf (*Hibiscus cannabinus L.*) is an annual herbaceous crop of the Malvaceae family with many environmental advantages and good mechanical properties. People have skillfully used kenaf since very old times, usually as rope, canvas, sack [8-10]. A considerable amount of literature has been published on kenaf and it has been used as an alternative raw material to wood in the pulp and paper industries to reduce the damage cause to the jungle [11, 12]. Kenaf plant includes three main parts: the flower, the outer fiber of stalk; "bast" or "bark" and the whiter, inner fiber of stalk; "core". The kenaf whole stalk and also bast fibers have many potential specific uses, including paper, textiles and composites. The chemical composition of kenaf is mostly including cellulose and lignin which the amount of cellulose in the bast is more than core [13-15].

Cellulose with molecular formula $C_6H_7O_2(OH)_3$ purifies from the cell walls of plants. It is a linear homopolymer (polysaccharide), composed of long, unbranched chains of 1, 4- β glucose units, as its monomer which contain alcoholic hydroxyl groups (OH). In cellulose, hydrogen bonded to adjacent glucose chains are forming microfibril polymers. The microfibrils provide rigidity and strength. Cellulose utilizes as filler in the production of some plastics, in fiber form as packing material and in pharmaceutical practice. The absence of side chains in cellulose allows these linear molecules to lie close together. Because of the many -OH groups, as well as the oxygen atom in the ring, there are many opportunities for hydrogen bonds to form between adjacent chains [13, 16-20]. Although the chemical structure of cellulose from different natural fibers is the same, the place of origin and climatic conditions affect the physicochemical properties of them [21]. Therefore, cellulose from kenaf tree is almost new material for production of biocomposites.

Due to infusibility and insolubility of cellulose, it is usually converted into derivatives to make it more processable. Some important derivatives of cellulose include ethers like methyl cellulose, esters such as cellulose acetate. However, a little attention has been given to these materials in efforts to develop biodegradable plastics. Slow degradation rates, high cost and processes which generate some noxious discharges are likely reasons [17, 22]. There are some good studies using cellulose derivatives in production of biocomposites, however, there is little literature about pure cellulose.

On the other hand, the most important problem associated with the processing of natural fiber-filled systems includes poor compatibility between the hydrophilic natural fiber and the hydrophobic matrix [23]. To overcome the major issue such as dispersion of fiber in the matrix and fiber-matrix interaction, plasticizers can be played as an important role in bonding of hydrophilic cellulose and hydrophobic PE. In fact, most of plasticizers are very hydrophilic and hygroscopic so they can attract OH groups of cellulose molecules and form a large hydrodynamic complex. Among plasticizers, PEG has been noted for being a biocompatible, lubricating, non-toxic, odorless, neutral, water-soluble, solvable in many organic solvent, nonvolatile and nonirritating and is used in a variety of applications [24, 25].

In addition, a major problem with natural fibers is their mechanical properties [14]. Most of the literature reviewed indicates that only a little work was done on pure cellulose and PE. Generally, most activities were done on composites containing lignocellulosic fibers and starch from different sources [26-29]. However, little work was done on fibers from kenaf as a fiber source. Additionally, there are almost no literature available on the cellulose reinforced composites and PEG as plasticizer for PE biocomposites. The study of Kaczmarek *et al.* [30] is an example which the mechanical properties of PP and cellulose (5-30%) composites tested are lower than those for PP alone but the influence of cellulose amount on the mechanical strength of composites is insignificant. Also, in investigation of mechanical properties of linear low-density poly (ethylene-co-butene) (PE) or maleated linear low-density poly (ethylene-co-butene) (M-PE) and cellulose composites, composites prepared with M-PE presented yield stress and elongation values higher than those of composites prepared with PE, showing the compatibilizer effect of maleic anhydride [31]. Nawang *et al.* [32] investigated the effect of filler volume fraction on the mechanical properties of sago starch and LLDPE biocomposites. The T_s and elongation at break decreased with increasing starch content, while the modulus increased. Also, the presence of high starch content (> 30%, w/w) had an adverse effect on the mechanical properties of LDPE/starch blends [33]. It has also been suggested that the increase of the starch amount into the LDPE matrix was responsible for the reduction on mechanical properties of the composites, in comparison with pure LDPE [34]. Unfortunately, most of these literature reviews are about starch, while it is a good source for human food.

As mechanical properties are very important for biopolymers, this paper is concerned with the methodology used for evaluating the mechanical properties of cellulose-LDPE composites, focusing on the tensile strength, flexural and izod impact key tests as well as morphology.

Experimental

Specimens Preparation: Kenaf, Variety V36, was obtained from INTROB, UPM. It was converted into kenaf fiber through following procedures [13]: the best part of the kenaf stems was separated from the core, were spread in the Lab and dried in the environmental condition for 2-3 days. The dried basts were then cut into small pieces and were put in the plastic bags. The samples were then ground using a Wiley Mill and were sieved using a shaker with pass 40 mesh (0.40 mm). The powder which passes through the 0.40 mm mesh is called kenaf fiber that was kept in the refrigerator for the next experiments.

After that, the cellulose extraction processing from kenaf fiber was carried out according to ASTM No.D1103-60 and using method of Han and Rowell [13]. The obtained cellulose was packaged under vacuum condition for using in the next steps.

Melt Blending: LDPE, 0.923 g/cm³density, 6.0 g/10min melt Index and 87.22 °C softening point was supplied from Titan Petchem (M) SDN. BHD [35]. The melt blending of LDPE and Cellulose were carried out by the blending machine with Rheomix at 120 °C, 10 minutes and 30 rpm rotor speed.

PEG with average molecular weight 8000 was provided from Sigma (Sigma-Aldrich). The requirement amounts of LDPE polymer, PEG and cellulose were placed in the cylinder mixer of blending machine with 3 cm diameter and 4.5 cm heights. According to categorization of biocomposite products [21], biocomposite formulation

is prepared based on medium biobased content product (21-50 % biobased content). The different formulations for producing of LDPE- cellulose biocomposites are shown in Table 1.

Compression-Molding: The composites obtained from melt blending were compressed using the Hot Press Machine for grounding of composite sheets. Composites were placed in the mold of size 15 cm × 15 cm with thickness of 1 mm at 120 °C, 5 minutes for molding time and the same for cooling time.

Mechanical Characteristics: Samples' dimensions for mechanical testing were prepared according to ASTM standards. To obtain the mechanical properties, tensile strength, flexural and impact izod tests were performed for all the specimens.

Tensile Properties All specimens with thickness 1 mm were cut into dumbbell-shaped according to the ASTM D63M-98. Tensile strength (Ts) was determined using 7 specimens for each composition by an Instron Universal Testing Machine 4302 with a load capacity of 1 KN. The cross-head speed was set at 5 mm/minute.

Izod Impact Test Impact bars were obtained by cutting specimens in rectangular- shaped. The size of these rectangular specimens was 3 mm thickness, 12 mm width and 62 mm length according to the ASTM D256-93a. Izod impact tests were conducted on an Izod impact tester using 7 un-notched specimens for each sample. Impact test is a method for determining behavior of materials when subjected to shock loading in bending, tension or torsion. The impact strength (Is) of composites depends on the amount of fiber and the type of testing method used (i.e. whether the samples were notched or unnotched). The Is of a notched specimen is less than that of an unnotched one. In unnotched specimens, the Is is defined in terms of the area under the stress-strain curve or as energy to break [36].

Table Error! No text of specified style in document.. Formulation of LDPE- cellulose- PEG composites

Cell content (Wt %)	PEG content (Wt %)	LDPE content (Wt %)	Cell weight (g)	PEG weight (g)	LDPE weight (g)
0	0	100	0.00	0.00	31.00
30	0	70	9.30	0.00	21.70
30	5 (%cell)	70	7.75	1.55	21.70
30	7 (%cell)	70	7.13	2.17	21.70
40	0	60	12.40	0.00	18.60
40	5 (%cell)	60	10.85	1.55	18.60
40	7 (%cell)	60	10.23	2.17	18.60
50	0	50	15.50	0.00	15.50
50	5 (%cell)	50	13.90	51.55	15.50
50	7 (%cell)	50	13.30	32.17	15.50

Note: cell = cellulose

Flexural Test Flexural strength (Fs) is maximum stress developed in a specimen just before it cracks or breaks in a flexure test[36]. Flexural testing by three-point bending of rectangular specimens is a simple test frequently performed and specified in ASTM D790 [37]. Tests were performed at room temperature by using an Instron Universal Testing Machine, with a load cell of 5 KN. The cross-head speed was set to 3 mm/minute. Fs was determined using 7 specimens for each composite formulation.

Surface Morphology Study SEM was employed to study the tensile and impact fracture surfaces of the biocomposite specimens. The specimens were coated with gold and then analyzed using a Philips XL 30 ESEM analyzer.

RESULTS AND DISCUSSION

Tensile Test: The interface between fiber (cellulose) and matrix influences the properties of composites. To distinguish effect of kenaf cellulose on the characteristics of biocomposites, the tensile properties was investigated and compared. Figure 1 shows the Ts of LDPE/cellulose biocomposites. It can be seen from this figure that there is a clear decreasing trend in the Ts as the cellulose loading increases from 0 to 50 wt%.

These findings further support the findings of Yang *et al.* [38] in which Ts of composites (PP/rice-husk flour) decreased as the filler loading increased.

As mentioned in the data sheet of the TitanGroup [35], the Ts of this LDPE polymer, grade LDI 305YY, is 10.76 MPa. From literature, the range of Ts for LDPE in food packaging is between 4 and 78.6 MPa [23]. The minimum acceptance level is plotted with black dot line at point 4, in Figure 2. Therefore, this study was set out with the aim of assessing the Ts of LDPE/cellulose biocomposites in the acceptance range. So, what is interesting in this data is that the use of kenaf cellulose up to 50 wt% in the production of biocomposites has reasonable tensile property. However, mixing of kenaf cellulose and PE in the blending machine was very difficult; it is probably because of the existence of two different polymeric and non-polymeric phases together in which cellulose being hydrophilic and LDPE polymeric matrix is hydrophobic. Thus, PEG was used as plasticizer in this study. To differentiate effects of cellulose and PEG on the characteristics of the biocomposites, the tensile properties was investigated and compared. Figure 2 indicates the Ts of the samples versus the different formulation of LDPE treatments.

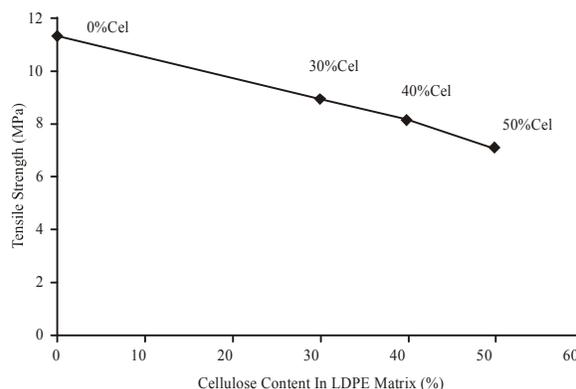


Fig. 1: Effect of kenaf cellulose (%) on tensile strength of biocomposite in LDPE Matrix

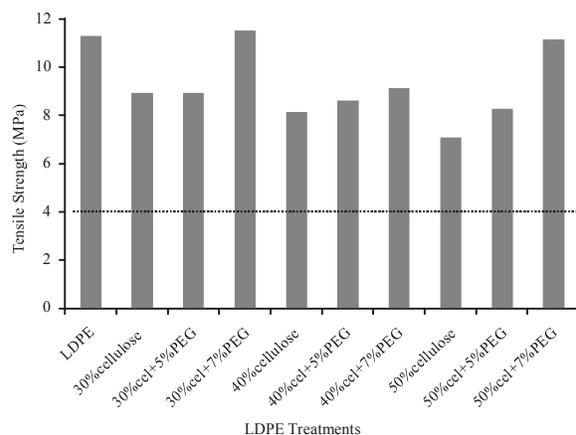


Fig. 2: Tensile strength of Cellulose and PEG content (%) in LDPE Matrix

Although PEG increases from 5% to 7%, Ts intensifies; it is apparent from this Figure that very few increasing was found in the Ts of composites content PEG, in comparison with LDPE. However, due to the flexibility and mobility of PEG, it increases the opportunity for good mixing of biocomposites in the blender machine. It is somewhat surprising that the Ts of none of biocomposites were noted out of acceptance level. Additionally, from this Figure (above) can be seen that LDPE treatments with 30% cellulose in company with 7% PEG and 50% cellulose plus 7% PEG have Ts proximity equal LDPE. These findings are agreement with those obtained by Yang *et al.* [39], who reported that the Ts of the composites (rice-husk flour reinforced PP) were significantly improved with the addition of the compatibilizing agent.

Chitosan were prepared by blending with polyols (glycerol, sorbitol and PEG) and fatty acids

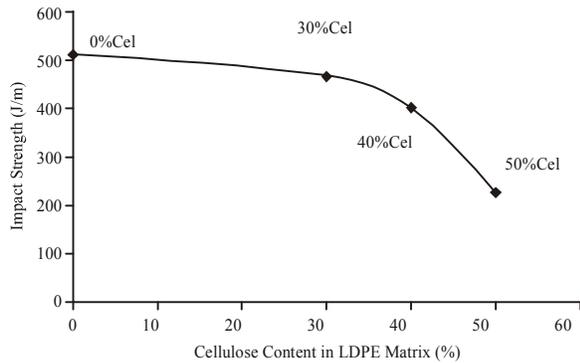


Fig. 3: Effect of kenaf cellulose (%) on unnotched Impact strength of biocomposite in LDPE Matrix

(stearic and palmitic acids) and their mechanical and barrier properties studied. The T_s of the blended films decreased with the addition of polyols and fatty acids [40].

Izod Impact Test: Impact test is designed to measure the ability of a sample to withstand a sudden shock. The effect of cellulose content on property of the unnotched Izod impact strength of LDPE matrix is shown in Figure 3. The I_s decreases as cellulose content increases in the composite. LDPE-cellulose biocomposites show lower values of I_s as compared to LDPE. It can be seen from Formula 1 that I_s is energy required to fracture a sample divided by thickness of sample. As the sample thickness is almost the same for all treatments, therefore, with increasing of cellulose in the biocomposite the required energy is decreased.

$$\text{Izod Impact strength (} I_s \text{)} = \frac{\text{Impact energy}}{\text{Specimen thickness}} \quad (1)$$

The present findings seem to be consistent with Yang *et al.* [38, 41] which found that notched and unnotched Izod impact strength of the composites [PP/rice-husk flour (RHF)] were lower due to the addition of rice-husk flour. On the other hand, a strong relationship between increasing filler loading and decreasing notched I_s of LDPE-RHF and LDPE-wood flour composites was reported by Yang *et al.* [41].

Besides, the interface between fiber (cellulose), plasticizer and matrix influences the properties of composites. The column chart in Figure 4 indicates the effect of PEG content (5 and 7%) on the I_s of LDPE-cellulose composites.

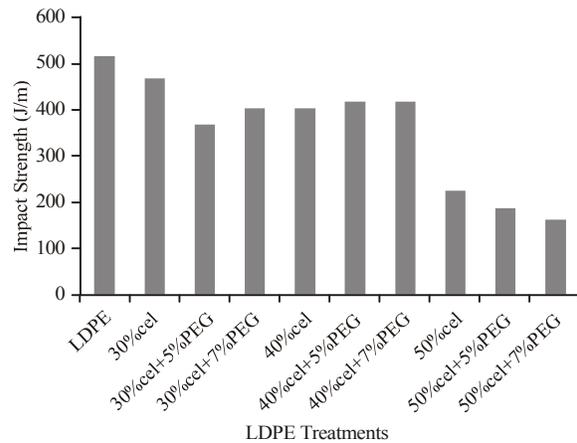


Fig. 4: Unnotched Impact strength of cellulose and PEG content in LDPE matrix

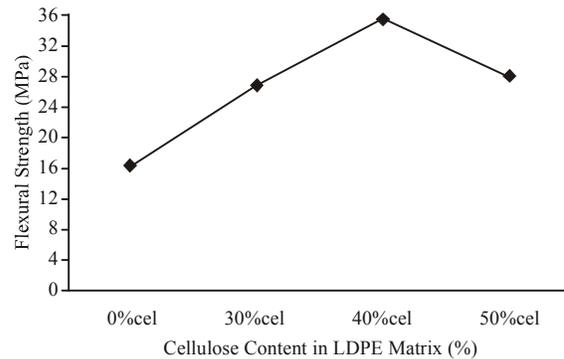


Fig. 5: Effect of Kenaf cellulose content on Flexural strength of LDPE biocomposites

From the graph above it can be seen that I_s of composites with 40% cellulose increases as the PEG content increases. Though, the amount of this factor in all LDPE-cellulose-PEG composites is lower than that determined for LDPE. However, the findings of the current study do not support the previous study [39] who reported that the both notched and unnotched Izod impact strength of the composites [rice-husk flour reinforced PP] decreased as the filler loading increased, but it was significantly improved with the addition of the compatibilizing agent.

Flexural Test: In order to evaluate the F_s of the incorporation of cellulose into the PE matrix, repeated measures of flexure test were done for LDPE composites. In fact, F_s is maximum stress developed in a specimen just before it cracks or breaks in a flexure test. Figure 5 presents the relationship between the average values of F_s and cellulose content in the LDPE matrix.

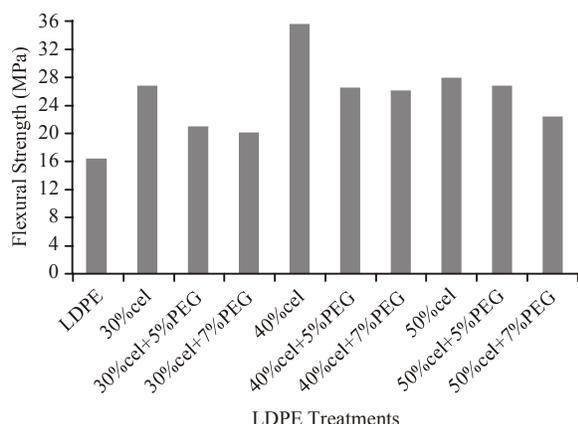


Fig. 6: Flexural Strength of cellulose and PEG content in LDPE matrix

This line diagram indicates that for 30 and 40% cellulose content in the LDPE matrix, cellulose-LDPE composites showed improvement in the Fs. For composition with 50% cellulose, a decreasing trend was observed. This result is in agreement with other study where there was a relationship between the Fs of rice husks (RH)-polyurethane-PEG200 composites and rice husks content in the composite [42]. In their study, Fs was increased as the RH loading increased up to approximately 45-60%. Exceeding this threshold value, the strength decreased.

The column diagram (Figure 6) indicates the Fs of composites versus different treatments of LDPE matrix.

From this graph it can be seen that there is no increase of Fs associated with addition of PEG to the biocomposites as compared with LDPE. However, biocomposites with 5% PEG have higher Fs than composites with 7% PEG.

Surface Morphology: SEM was carried out to determine the dispersion of fiber in the matrix, adhesion between fiber and matrix and to detect the presence of any micro defect. In fact, SEM can support the findings of tensile properties. Figure 7 shows SEM micrograph of the fracture surfaces in the LDPE-cellulose biocomposites.

In Figure 7, LDPE formed a continuous phase with cellulose fibers randomly distributed. However, the SEM micrographs revealed a certain number of pulled-out traces on the fracture surfaces of the test samples fabricated using cellulose and LDPE. It may be noted that the LDPE-cellulose interface does not present homogeneity due to the opposite nature of the components (hydrophobic LDPE versus hydrophilic cellulose). As the cellulose content increases in the

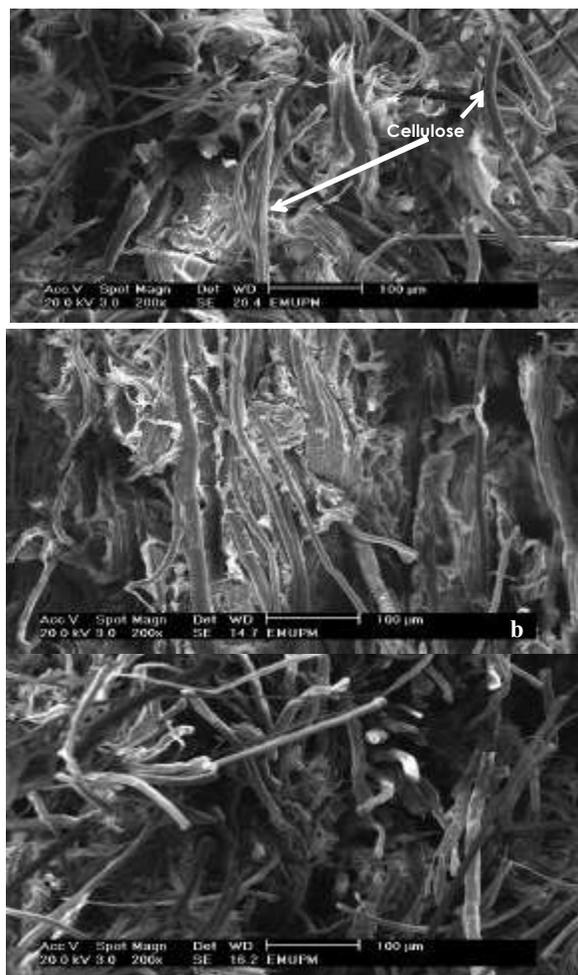


Fig. 7: SEM (Mag. × 200) for fracture surface of LDPE-cellulose composites at different concentrations: a) 70:30, b) 60:40 and c) 50:50

composites the fiber pull-out enhances. Nakamura *et al.* [34] demonstrated that a lack of good interface of LDPE/starch results in bad homogeneity of composite due to the opposite nature of the hydrophobic LDPE versus hydrophilic starch.

Generally, SEM micrographs of fracture surfaces of different LDPE-cellulose composites clearly indicate that the differences in microstructure of the various composites are significant, as shown in Figure 7, for untreated composite and Figure 8, for composite treated with PEG. It is apparent from Figure 8, adding plasticizer (PEG) to composite enhances their dispersion in the continuous LDPE phase and it facilitates the direct contact between the cellulose fibers and LDPE matrix. It may be noted that PEG helps to make a stronger interfacial bonding between LDPE and cellulose. As shown in

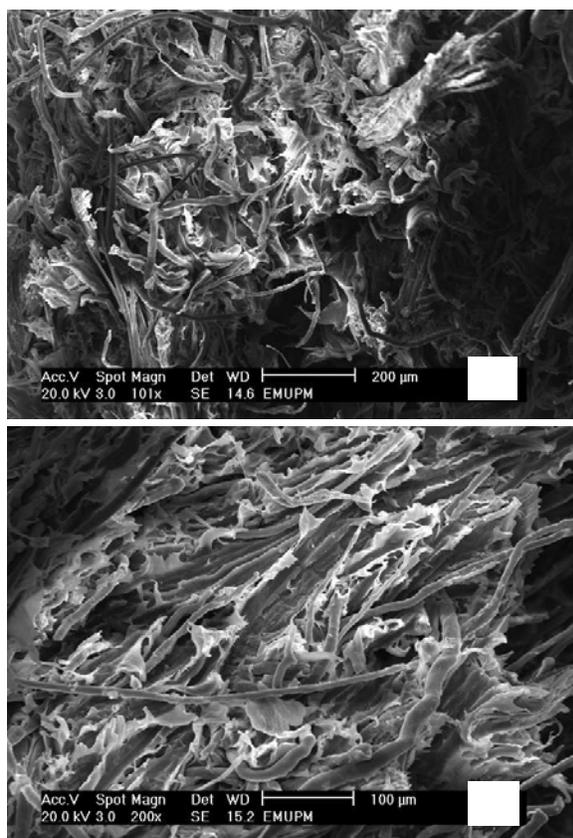


Fig. 8: SEM for tensile fracture surface of LDPE-cellulose-PEG composites; a) 30%Cel+7%PEG (Mag. \times 101) and b) 50%Cel+7%PEG (Mag. \times 200)

Figure 8, better homogeneity is observed in the composites with 30% Cellulose in conjunction with 7% PEG (a) and 50% Cellulose plus 7% PEG (b). This means that the SEM results support the findings of tensile properties.

CONCLUSION

The present study was designed to determine the effect of cellulose of kenaf fiber on the mechanical behavior of LDPE -cellulose biocomposites. In general, this study has found that as the cellulose loading increases in the LDPE -cellulose composites, because of the increase in the interfacial area and the interfacial bonding between the hydrophilic cellulose and hydrophobic LDPE decrease the mechanical properties. Although, the tensile strength of the composites was decreased slightly as the cellulose content increased, the strength of bio-composites retained an acceptable level of strength for food packaging.

The SEM micrographs revealed a certain number of pulled-out traces on the fracture surfaces of the test samples using cellulose and LDPE polymers, but less pulled-out traces on the fracture surfaces of the test samples using PEG as the plasticizer, due to the stronger interfacial bonding. It may be noted that the LDPE - cellulose interface does not present very good homogeneity due to the opposite nature of the components. In the case of treated composites with PEG, the fiber-matrix adhesion seems to be better. The tensile strength clearly decreases as the cellulose content increases, in both untreated and PEG composites. However, it is considerably greater in untreated composites than PEG treated composites. Therefore, the use of PEG certainly enhances the adhesion capacity at the interface. Consequently, both of cellulose content and PEG influence the tensile strength. The results of a morphological study revealed that the positive effect of plasticizer on interfacial bonding of cellulose and polymer that improved their processabilities.

REFERENCES

1. Han, J.H., 2005. New technologies in food packaging: overview in *In Innovations in Food Packaging* (Han, J. H., ed) pp. 3-11, Elsevier Academic Press,
2. Brown, W.E., 1992. *Plastics in food packaging: properties, design and fabrication*, Marcel Dekker, Inc., New York.
3. Abd El-Rehim, H.A., E.S.A. Hegazy, A.M. Ali and A.M. Rabie, 2004. Synergistic effect of combining UV-sunlight-soil burial treatment on the biodegradation rate of LDPE/starch blends, *Journal of Photochemistry and Photobiology A: Chemistry*, 163: 547-556.
4. Espert, A., F. Vilaplana and S. Karlsson, 2004. Comparison of water absorption in natural cellulosic fibres from wood and one-year crops in polypropylene composites and its influence on their mechanical properties, *Composites. Part A, Applied Science and Manufacturing*, 35: 1267-1276.
5. Weber, C.J., 2000. Biobased packaging materials for the food industry, status and perspectives in, *A European Concerted Action*.
6. Piringer, O.G. and A.L. Baner, 2000. *Plastic packaging materials for food*, WILEY-VCH Press.
7. Hanlon, J.F., R.J. Kelsey and H.E. Forcinio, 1998. *Handbook of package engineering*, CRC Press.

8. Bismarck, A., S. Mishra and T. Lampke, 2005. Plant fibers as reinforcement for green composites in *Natural fibers, biopolymers and biocomposites* (Mohanty, A. K., Misra, M. and Drzal, L. T., eds) pp: 37- 108, CRC Press.
9. Keshk, S., W. Suwinarti and K. Sameshima, 2006. Physicochemical characterization of different treatment sequences on kenaf bast fiber, *Carbohydrate Polymers*, 65: 202-206.
10. Siepe, T., D. Ventrella and E. Lapenta, 1997. Evaluation of Genetic Variability in a Collection of *Hibiscus cannabinus* (L.) and *Hibiscus* spp (L.), *Industrial Crops and Products*, 6: 343-352.
11. FAO. 1989. Impact of changing technological and economic factors on markets for natural industrial fibres case studies on jute, kenaf, sisal and abaca, Food and Agriculture Organization of the United Nations, FAO economic and social development, pp: 77-74.
12. Theivendirajah, K., 1981. Studies of the fibers of kenaf (*Hibiscus cannabinus*), used in papermaking, *Cylon journal of science, Biological Science*, 14: 7-9.
13. Han, J.S. and J.S. Rowell, 1996. Chemical composition of fibers. In *Paper and Composites from Agro-Based Resources* (Rowell, R. M. and Rowell, J., eds) pp: 83-130. CRC Press,
14. Nishino, T., 2004. Natural fiber sources in *Green Composites, Polymer Composites and the Environment* (Baillie, C., ed) pp: 49-80, CRC Press
15. Sanadi, A.R., D.F. Caulfield, K. Walz, L. Wieloch, R.E. Jacobson and R.M. Rowell, 1994. Kenaf fibers - Potentially outstanding reinforcing fillers in thermoplastics. Paper presented at the Sixth Annual International Kenaf Conference, New Orleans, LA.
16. Berglund, L. 2005. Cellulose-based nanocomposites. In *Natural fibers, biopolymers and biocomposites*, ed. pp: 807-832.. in *Natural fibers, biopolymers and biocomposites* (Mohanty, A. K., Misra, M. and Drzal, L. T., eds) pp: 807-832, CRC Press,
17. Chandra, R. and R. Rustgi, 1998. Biodegradable polymers Program *Polymer science, progress in polymer science*, 23: 1273-1335.
18. Herrera, F., J. Pedro and A. Valadez-Gonzalez, 2005. Fiber- matrix adhesion in natural fiber composites in *Natural fibers, biopolymers and biocomposites* (Mohanty, A. K., Misra, M. and Drzal, L. T., eds) pp: 177- 230, CRC Press,
19. Kokta, B.V., 1988. Bonded composites of cellulose based fibres in polystyrene polymers characterised by a bonding agent: (B. V. Kokta of Canada) GB 2193 503 A (10 February 1988), *Composites*, 19: 331-331.
20. Kompella, M.K. and J. Lambros, 2002. Micromechanical characterization of cellulose fibers, *Polymer Testing*, 21: 523-530.
21. Mohanty, A., K. Misra, L.T. Drzal, S.E. Selke, B.R. Harte, and G. Hinrichsen, 2005. Natural fibers, biopolymers and biocomposites: an introduction in *Natural fibers, biopolymers and biocomposites* (Mohanty, A. K., Misra, M. and Drzal, L. T., eds) pp: 1- 36. CRC Press,
22. Selke, S.E., 2000. Plastics recycling and biodegradable plastics in *Modern plastics handbook* (Harper, C. A., ed) pp: 12.1-12.108, McGraw - Hill.,
23. Sain, M. and S. Panthapulakkal, 2004. Green fiber thermoplastic composites in *Green Composites, Polymer Composites and the Environment* (Baillie, C., ed) pp: 181-206, CRC Press,
24. Kawai, F., 2003. Biodegradation of polyethers (polyethylene glycol, polypropylene glycol, polytetramethylene glycol and others) in *Biopolymers* (Matsumura, S. and Steinbuchel, A., eds) pp: 267-298, Wiley-VCH,
25. Shalaby, S.W. and M. Shalaby, 2003. Polyethylene glycol-based copolyesters in *Absorbable and Biodegradable Polymers* (Shalaby, W. S. and Burg, K. J. L., eds) pp: 40, CRC Press,
26. Cazaauranc-Martinez, M.N., P.J. Herrera-Franco, P.I. Gonzalez-Chi and M. Aguilar-Vega, 1991. Physical and mechanical properties of Henequen fibers, *J. Appl. Polym. Sci.*, 43: 749.
27. Nhan, L.G. and E.F. Denby, 1979. A short note on the variation in mechanical properties of individual filaments of jute and kenaf, *Journal Textile Institute*. 10: 262-268.
28. Page, D.T. and F. El-Hosseiny, 1983. The mechanical properties of single wood pulp fibers. Part VI: Fibril angle and the shape of the stress-strain curve, *J. Pulp Paper Sci.*, 9: 99-100.
29. Wollerdorfer, M. and H. Bader, 1998. Influence of natural fibers on the mechanical properties of biodegradable polymers, *Ind. Crop. Prod.*, 8: 105-12.
30. Kaczmarek, H., D. Oldak, P. Malanowski and H. Chaberska, 2005. Effect of short wavelength UV-irradiation on ageing of polypropylene/cellulose compositions, *Polymer Degradation and Stability*, 88: 189-198.

31. Kosaka, P.M., Y. Kawano, H.M. Petri, M.C.A. Fantini and D.F.S. Petri, 2007. Structure and properties of composites of polyethylene or maleated polyethylene and cellulose or cellulose esters, *Journal of Applied Polymer Science*, 103: 402-411.
32. Nawang, R., I.D. Danjaji, U.S. Ishiaku, H. Ismail and Z.A. Mohd Ishak, 2001. Mechanical properties of sago starch-filled linear low density polyethylene (LLDPE) composites, *Polymer Testing*, 20: 167-172.
33. Arvanitoyannis, I., C.G. Biliaderis, H. Ogawa and N. Kawasaki, 1998. Biodegradable films made from low-density polyethylene (LDPE), rice starch and potato starch for food packaging applications: Part 1, *Carbohydrate Polymers*, 36: 89-104.
34. Nakamura, E.M., L. Cordi, G.S.G. Almeida, N. Duran, and L.H.I. Mei, 2005. Study and development of LDPE/starch partially biodegradable compounds, *Journal of Materials Processing Technology*, pp: 162-163, 236-241.
35. Titan Group, 2007. TITANLENE® LDI 305YY in *Titan Group data sheet*, <http://prospector.ides.com/datasheet.aspx?I=34andE=80396>, May/06/2007.
36. Nielsen, L.E. and R.F. Landel, 1994. *Mechanical properties of polymers and composites*, Second edition edn, Marcel Dekker, Inc., New York.
37. Miller, E., 1996. *Introduction to plastics and composites, Mechanical properties and engineering applications*, Marcel Dekker, Inc., New York.
38. Yang, H.S., H.J. Kim, J. Son, H.J. Park, B.J. Lee and T.S. Hwang, 2004. Rice-husk flour filled polypropylene composites; mechanical and morphological study. *Composite structures*, *Composite Structures*, 63: 305-312.
39. Yang, H.S., H.J. Kim, H.J. Park, B.J. Lee and T.S. Hwang, 2007. Effect of compatibilizing agents on rice-husk flour reinforced polypropylene composites, *Composite Structures*, 77: 45-55.
40. Srinivasa, P.C., M.N. Ramesh and R.N. Tharanathan, 2007. Effect of plasticizers and fatty acids on mechanical and permeability characteristics of chitosan films, *Food Hydrocolloids*, 21: 1113-1122.
41. Yang, H.S., M.P. Wolcott, H.S. Kim, S. Kim and H.J. Kim, 2006. Properties of lignocellulosic material filled polypropylene bio-composites made with different manufacturing processes, *Polymer Testing*, 25: 668-676.
42. Rozman, H.D., Y.S. Yeo, G.S. Tay and A. Abubakar, 2003. The mechanical and physical properties of polyurethane composites based on rice husk and polyethylene glycol, *Polymer testing*, 22: 617-623.