

MECHANICAL AND THERMAL CHARACTERIZATION OF BANANA PEEL FIBERS/HDPE COMPOSITES

P. H. F. Pereira^{1*}, C.Y. Watashi¹, T. Brocks¹, K. C.C.C. Benini¹, H. J. C. Voorwald¹, M. O. H. Cioffi¹

¹ *Fatigue and Aeronautical Research Group, Materials and Technology, Univ. Estadual Paulista, Ariberto Pereira da Cunha Ave., 333 – Guaratinguetá – SP - Brazil*

**fernandes_eng@yahoo.com.br*

Keywords: Peel banana fibers, tensile tests, thermogravimetric analysis, and high density polyethylene.

Abstract

Lignocellulosic fibers from banana peels were washed with water in order to increase its compatibility with polymeric matrix. These fibers were mixed with high density polyethylene (HDPE) and placed in an injector chamber in order to obtain specimens for tensile tests. Samples of HDPE/washed banana fibers composites were characterized by tensile tests and thermal analysis. Results showed that the addition of washed banana fibers decreased the thermal stability of composites; on the other hand increased the melting and crystallization temperatures of composites. The addition of 5% of fibers also provided an improvement in the mechanical properties of composites in comparison with the pure HDPE.

1 Introduction

There is a world tendency in using natural renewable alternative resources that can benefit man in creating new materials. Nowadays, the researchers are looking forward the development of new material that attends the socioeconomic needs as much as environmental problems [1]. For this reason, the development and applications of lignocellulosic composites are being more explored, as a good alternative on the past decades [2].

Natural fibers as reinforcement for polymeric matrices have been studied during decades due to many advantages gained and environmental performance when compared to inorganic fibers, such as glass and carbon fibers [3-5]. The main advantages presented by these fibers are: abundance and therefore low cost, biodegradability, flammability, flexibility during processing, low density, relatively high tensile and flexural modulus and non-toxicity [3, 6-8]. In tropical countries like Brazil, fibrous plants are available in abundance, among these plants can highlight the banana tree which is typically from tropical and subtropical regions, therefore, need constant heat and high humidity for its proper development and production, characteristics that are found in regions near the Brazilian coast and in Asian countries, especially in India [5, 10].

According to date obtained from Embrapa [9], Brazil is the 5th country in the banana production of the world, with a production of 6.783.480 tons in 479.614 hectares (hc) in 2009 (Table1).

World consumption of banana fruit is of 10.43 kg/inhabitant/year, the largest consumers are the South Americans country with 21.23 kg/inhabitant/year. Occupying second place is Central America with 13.90 kg/inhabitant/year and in third Oceania with 11.26 kg/capita/year

[11].Despite the large consumption of bananas and hence the large amount of peels that are generated, there are few industrial uses for the banana peels, which represents 30-40% by weight of fruit [12].

Country	Area(hc)	Production (ton)	Yield (ton/hc)
India	748.100	26.996.600	36,09
Philippines	446.400	9.013.190	20,19
China	350.224	9.006.450	25,72
Ecuador	216.115	7.637.320	35,34
Brazil	479.614	6.783.480	14,1
Others	2.683.131	37.941.232	14,14
World	4.923.584	97.378.272	19,78

Table 1. Production of banana per country in 2009 [9].

Some attempts to apply this residue were done in protein production, methane, ethanol, pectins, and enzyme extracts. It has also been used as livestock feed and heavy metal bioabsorbents, dyes, and as removal of phenols compounds [12-15]. On the other hand no publication was found on the use of fibers of banana peel as reinforcement in polymer composites.

In the literature a lot of authors [1,2,5,16] studied the use of fiber extracted from banana pseudostem as reinforcement in polymer composites, Ibrahim et al. [2], for example, studied the banana fiber and its micro fibrils, extracted from pseudostem, as reinforcement in polymer composites of HDPE, using alkaline treatments and different amounts of fiber immersed in the matrix, and concluded that increased adherence results in improved mechanical properties. In the use of natural fibers, from different natural resources, as reinforcement in polymeric composites, the biggest problem identified is the poor compatibility between fibers and matrix.

In order to optimize this fiber/matrix interface and to promote adhesion, various chemical treatments can be applied on the surface fibers such as alkaline treatment, bleaching, acetylation and steaming [17,18].(Rosa et al., 2009; Bessadok et al., 2009).

Among these treatments, the chemical treatments are the most commonly applied and have the main objective remove amorphous material as lignin, waxes and extractives, which makes fiber incompatible with polymeric matrices, when used as reinforcement in composites [19]. However, according to Oliveira et al. [1] the application of chemical surface treatments has been limited in industrial applications due to problems related to the high cost of the treatment and the disposal of the chemical products used.

Inside these context in the present work the usual chemical treatments was changed by a simple washing with water in order to simplify and decrease the cost of this step and them evaluate if the washing with no chemical reagents is sufficient to improve the compatibility between fibers and matrix.

The fibers obtained from the banana peels washed with water were incorporated into HDPE through processes of mixture into thermokinetic mixer and injection molding for manufacture of composite materials.

HDPE as well as composites were characterized by thermal analysis and tensile test to evaluate the effect of addition of the fibers in the thermal and mechanical properties of the composites.

2 Materials and methods

2.1 Materials

Banana peels fibers, namely banana fibers, were obtained from a residue of banana fruit (*Musa*, genotype AAB). Firstly banana peel were separated, dried at 50°C for 48 hours, after being crushed on common processor, and finally sieved until 50 mesh (opening 300 mm/μm). High density polyethylene (HDPE), designated HI-60070, was supplied by Riopol and used as matrix for composites.

2.2 Fiber treatment

Banana peel fibers were washed with distilled water (50 g crushed fiber/500 mL water) for 10 minutes at room temperature. Once the time of washing was reached, the solution was filtered in a vacuum filter and fibers were dried in an oven at 50°C (122 °F) for 48 hours. Figure 1 shows the images of banana fibers before and after the washing with water.

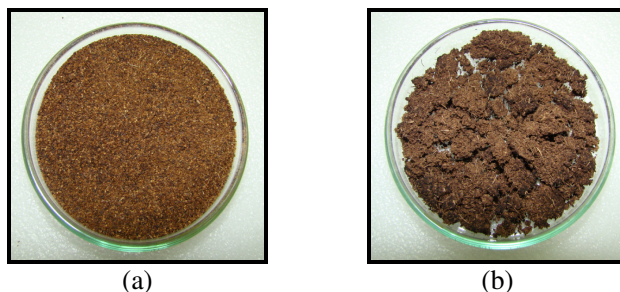


Figure 1. (a) Banana fiber (BF) and (b) washed banana fiber (WBF).

2.3 HDPE/Banana fibers composites preparation

The washed banana fibers (WBF) were mixed with the high density polyethylene (HDPE) in a thermokinetic mixer model MH-50H, with the speed rate kept at 5250 rpm, in which fibers were responsible for 5 and 10 wt% of the composition. After mixing, composites were dried and ground in a mill model RONE. Then, HDPE/banana fibers composites were placed in an injector chamber at 165°C (329 °F) and heated at a 2 °C.min⁻¹ (35.6 °F.min⁻¹). The melted material was injected in required dimensions, in a pre-warm mold in order to obtain tensile specimens. Pure HDPE specimens were submitted on the same process for comparison.

2.4 Thermogravimetry

Thermogravimetric analysis (TGA/DTG) was performed in a study of the thermal characteristics of banana fibers/HDPE composites. Thermal behavior was determined using a Shimadzu TGA-50 model, in open platinum crucible with heating at 20 °C/min in 50 mL/min flow of nitrogen in a temperature range between 25 °C and 900 °C.

Differential scanning calorimetric analyses (DSC) of composites were performed on a DSC calorimeter Seiko under nitrogen atmosphere. The samples were heated to 300 °C then cooled to 25 °C and after heated again to 300 °C, with a heating rate of 10 °C/min, to eliminate previous thermal history.

The glass transition temperatures were determined using ASTM D 3418-08 [20]. The method used was extrapolation, by drawing two lines parallel to the curves before and after increasing the flow of heat at temperatures between 60 °C and 70 °C.

Tensile Tests of Composites

Five specimens of each composite and pure HDPE were tested in a “Instron” universal testing machine (model 8801). Tensile tests were carried out according to ASTM D638 (Type I) [21] at a crosshead speed of 10 mm/min using 100kN load cell without extensometer.

3 Results

With the characterization by thermogravimetric has been possible to establish the degradation temperatures and the effect of fibers addition on the thermal stability of the composites.

The TGA and DTG curves for HDPE and its composites with 5% and 10% of washed banana fibers are presented in the Figures 2 and 3.

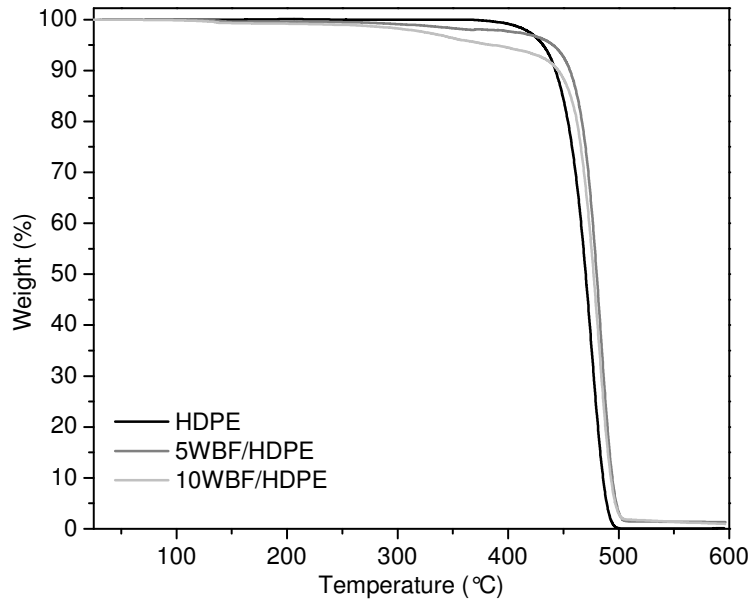


Figure 2. Thermogravimetical analysis for HDPE and WBF/HDPE composites, TGA curves.

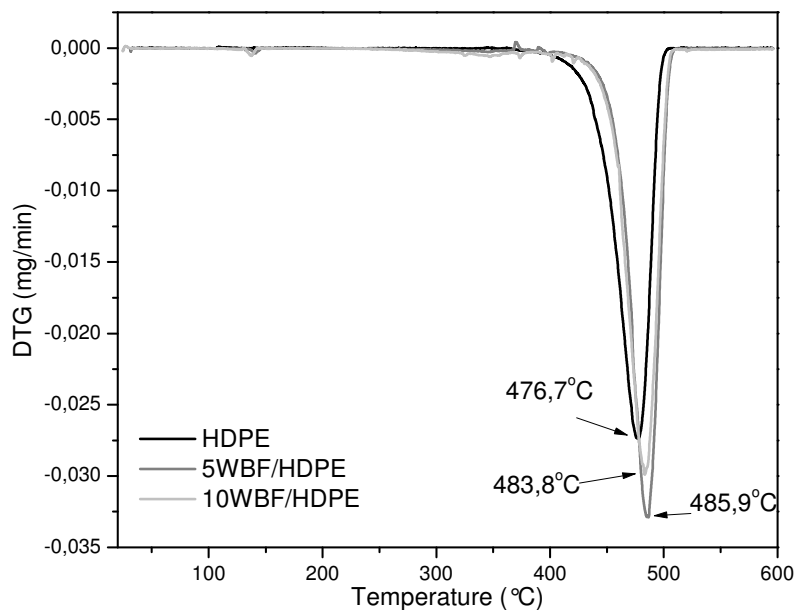


Figure 3. Thermogravimetical analysis for HDPE and WBF/HDPE composites, DTG curves.

Analyzing the TGA curves is possible to observe that HDPE is thermally stable up to a temperature of 350 °C. From this temperature, the procedure of thermal decomposition of HDPE occurred in only one stage until 500 °C.

With the addition of washed banana fibers it was verified a slight reduction in thermal stability of the material and, the degradation process occurred in two distinct stages. The first stage occurred between 300 and 400 °C, related to decomposition of the fibers and almost imperceptible in DTG curves due to the small amount of reinforcement used (5 and 10%), and the second one occurred between 300 °C and 550 °C, with peaks at 476.7 °C, 485.9 °C and 483.8 °C for HDPE, 5WBF/HDPE and 10WBF/HDPE respectively.

The initial degradation and the residue obtained at the end of the degradation process are summarized in Table 2. Analyzing the data, it is possible to observe that the addition of WBF in the pure polymer has increased the amount of residue in the end of the thermal degradation due to decomposition of some components of the fiber which presents initial degradation temperature above 600 °C.

Samples	T _{degradation} (°C)	Residue (%) 600°C
HDPE	380,1	0,01
5WBF/HDPE	272,9	1,1
10WBF/HDPE	238,3	0,7

Table 2. Weight loss and degradation pecks for HDPE and its composites.

The melting and crystallization behavior of the composites and the pure HDPE, obtained from DSC analysis, are shown in the curves of the Figures 4 and 5, and the quantitative results are summarized in Table 3.

Samples	T _g (°C)	T _c peack (°C)	T _m peack (°C)	ΔH _m (J.g-1)	X _c (%)
HDPE	59,5	86,7	104,5	188,3	64,3
5WBF/HDPE	60,3	116,5	135,2	183,1	65,8
10WBF/HDPE	61,4	116,3	134,0	183,9	69,7

* T_g: glass transition temperature, T_c: crystallization temperature and T_m: melting temperature.

Table 3. Melting and crystallization parameters of HDPE and WBF/HDPE obtained from DSC measurements.

The crystallinity index (X_c) for HDPE and its composites was evaluated from the Equation 1:

$$X_c = \frac{\Delta H_m * 100}{\Delta H_m^0 * w} \quad (1)$$

where X_c is the crystallinity index, ΔH_m is the melting enthalpy of sample, ΔH_m⁰ is the standard melting enthalpy and w is the weight fraction of HDPE in the composite. The value of ΔH_m⁰ obtained for HDPE is 293 J.g-1.

The glass transition temperature of HDPE matrix in the composite do not present significant differences compared to pure HDPE, in the other hands with the addition of fibers it can be seen that the temperatures of melting and crystallization as well as the crystallinity index increased compared to pure HDPE because the fiber provide greater ordering of the internal structure in the composite.

The melting peak temperatures (T_m) of HDPE in the composites presented a slight decrease with the increase of fiber content. According to Choudhury [22] the occurrence of lower melting peak can be attributed to the fact that a strong nucleation on the fibers surfaces

shortened the time of HDPE crystallization, leading a formation of smaller crystals and therefore, favoring the decrease of melting temperature.

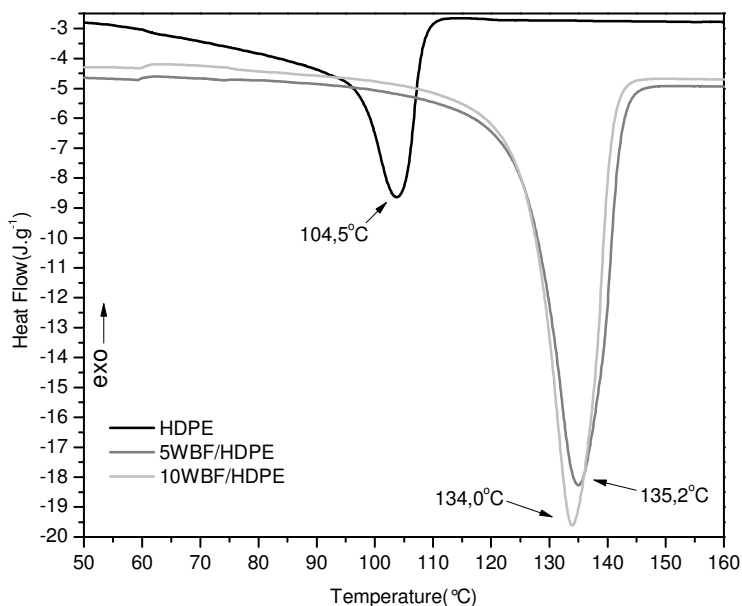


Figure 4. DSC second heating run of HDPE, 5WBF/HDPE and 10WBF/HDPE.

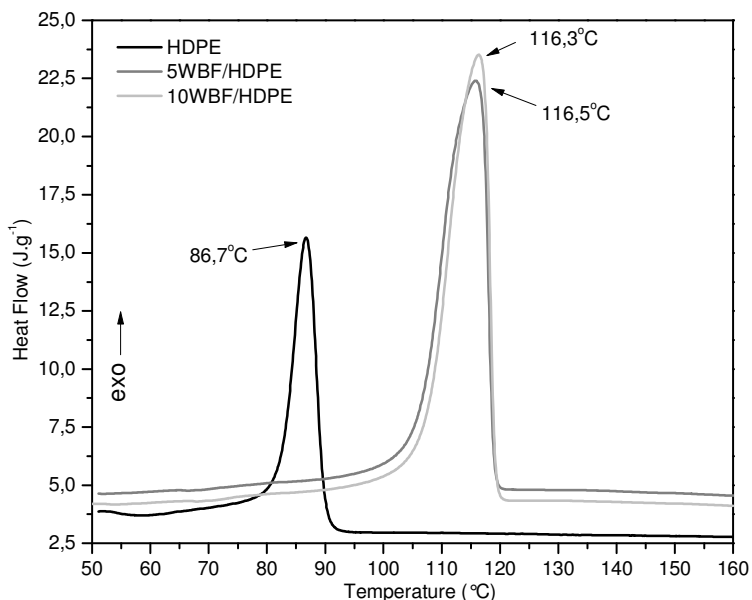


Figure 5. DSC cooling run of HDPE, 5WBF/HDPE and 10WBF/HDPE.

Mechanical properties such as elongation at break, tensile strength, and tensile modulus for HDPE and its composites with 5% and 10% of WBF are presented in Table 4.

Analyzing the results of Table 4 it was observed that the composites presented better tensile strength compared to pure HDPE. However, the composites reinforced with 5% (w/w) of fiber showed tensile strength about 7% higher than the composite reinforced with 10%, which can be seen as an indicative that the addition of more than 5% of fiber in the composites decreases their mechanical properties, which limiting the use of a maximum of 5% of reinforcement.

Samples	Elongation (%)	Tensile Strength (MPa)	Tensile Modulus (MPa)
HDPE	2,1 ± 0,3	15,7 ± 1,1	732,5 ± 90,6
5WBF/HDPE	2,3 ± 0,1	19,1 ± 0,6	814,5 ± 8,5
10WBF/HDPE	2,4 ± 0,1	18,2 ± 0,4	760,5 ± 5,3

Table 4. Mechanical properties of WBF/HDPE composites.

Conclusions

The addition of washed banana fiber in the HDPE decreased the thermal stability of composite and increased the residue at the final of degradation process. Melting and crystallization temperatures as well as crystallinity index also increased with addition of fiber in polymeric matrix. About mechanical properties, addition of washed banana fibers increased the tensile strength and tensile modulus of composites and, limited the amount of fibers in 5%, since the higher amount of reinforcements lead to lower values of these mechanical properties.

References

- [1] Oliveira, F.R., Erkens, L., Fangueiro, R., Souto, A.P. Surface modification of banana fibers by DBD plasma treatment. *Plasma Chemistry and Plasma Processing*, **32**, pp. 259-273 (2012).
- [2] Ibrahim, M.M., Dufresne, A., El-Zawawy, W.K., Agblevor, F.A. Banana fibers and microfibrils as lignocellulosic reinforcements in polymer composites, *Carbohydrate Polymers*, **81**, pp. 811-819 (2010).
- [3] Xie, Y., Hill, C.A.S., Xiao, Z., Militz, H., Mai, C. Silane coupling agents used for natural fiber/polymer composites: A review. *Composites Part A*, **41**, 806-819 (2010).
- [4] Awal, A., Cescutti, G., Ghosh, S. B., Müssig, J. Interfacial studies of natural fibre/polypropylene composites using single fibre fragmentation test (SFFT). *Composites Part A*, **42**, pp. 50-56 (2011).
- [5] Venkateshwaran, N., ElayaPerumal, A., Arwin Raj, R.H. Mechanical and dynamic mechanical analysis of woven banana/epoxy composite. *Journal Polymer Environment*, in press (2012).
- [6] Qin, L., Qiu, J., Liu, M., Ding, S., Shao, L., Lü, S., Zhang, G., Zhao, Y., Fu, X. Mechanical and thermal properties of poly(lactic acid) composites with rice straw fiber modified by poly(butyl acrylate). *Chemical Engineering Journal*, **166**, pp. 772-778 (2011).
- [7] Antich, P., Vázquez, A., Mondragon, I., Bernal, C. Mechanical behavior of high impact polystyrene reinforced with short sisal fibers. *Composites Part A*, **37**, pp.139-150 (2006).
- [8] Kim, J.T., Netravali, A.N. Mercerization of sisal fibers: Effect of tension on mechanical properties of sisal fiber and fiber-reinforced composites. *Composites Part A*, **41**, pp. 1245-1252 (2010).
- [9] Embrapa - Brazilian Agricultural Research Corporation. 2010. Available: <www.embrapa.br.> Accessible: 2011 july 29.
- [10] CEPEA - Centro de Estudos Avançados em Economia Aplicada. Banana: mercado atual e perspectivas do setor. Available: <www.cepea.esalq.usp.br>. Accessible: 2011 october 30.
- [11] VIEIRA, L. M., Síntese anual da agricultura de Santa Catarina 2009-2010. Santa Catarina: EPAGRI/CEPA, 2010.
- [12] Albarelli, J.Q., Rabelo, R.B., Santos, D.T., Beppu, M.M., Meireles, M.A.A. Effects of supercritical carbon oxide on waste banana peels for heavy metal removal. *The Journal of supercritical Fluids*, **58**, pp. 343-351 (2011).

- [13] Achak, M.; Hadifi, A.; Ouazzani, N.; Sayadi, S.; Mandi, L. Low cost biosorbent "banana peel" for the removal of phenolic compounds from olive mill waste water: kinetic and equilibrium studies. *Journal of Hazardous Material*, **166**, pp. 117-125 (2009).
- [14] Anwar, J.; Shafique, U.; Zaman, W. U.; Salman, M.; Dar, A.; Anwar, S. Removal of Pb (II) and Cd (II) from water by absorption on peels of banana. *Bioresource Technology*, **101**, pp. 1752-1755 (2010).
- [15] Comim, S. R. R.; Madella, K.; Oliveira, J. V.; Ferreira, S. R. S. Supercritical fluid extraction from dried banana peel (*Musa spp.*, genomic group AAB): Extraction yield, mathematical modeling, economical analysis and phase equilibria. *The Journal of Supercritical Fluids*, **54**, pp. 30-37 (2010).
- [16] Guimarães, J.L., Wypych, F., Saul, C.K., Ramos, L.P., Satyanarayana, K.G. Studies of the processing and characterization of corn starch and its composites with banana and sugarcane fibers from Brazil. *Carbohydrate Polymers*, **80**, pp. 130-138 (2010).
- [17] Bessadok, A., Roudesli, S., Marais, S., Follain, N., Lebrun, L. Alfa fibres for unsaturated polyester composites reinforcement: Effects of chemical treatments on mechanical and permeation properties. *Composites: Part A*, **40**, pp. 184-195 (2009).
- [18] Rosa, M.F., Chiou, B., Medeiros, E.S., Wood, D.F., Williams, T.G., Mattoso, L.H.C., Orts, W.J., Imam, S.H. Effect of fiber treatments on tensile and thermal properties of starch/ethylene vinyl alcohol copolymers/coir biocomposites. *Bioresource Technology*, **100**, pp. 5196-5202 (2009).
- [19] Carvalho, K.C.C., Mulinari, D.R., Voorwald, H.J.C., Cioffi, M.O.H. Chemical modification effect on the mechanical properties of HIPS/ coconut fiber composites. *Bioresources*, **5**, pp. 1143-1155 (2010).
- [20] ASTM D 3418. *Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry* (2008).
- [21] ASTM D 638. *Standard Test Method for Tensile Properties of Plastics* (2008).
- [22] Choudhury, A. Isothermal crystallization and mechanical behavior of ionomer treated sisal/HDPE composites. *Materials Science and Engineering A*, **491**, pp. 492-500 (2008).