[10] M. G. Song, *et al.*: Compos Struct, vol. 92 (2010), p. 2194-2202.
[11] A. Deb, *et al.*: Int J Adhes Adhes, vol. 28 (2007), p. 1-15.
[12] L. Grant, *et al.*: Int J Adhes Adhes, vol. 29 (2009), p. 405-413.
[13] J. Comyn: Intl J Adhes Adhes, vol. 10 (1990), p. 161-165.
[14] T. Katona and S. Batterman: Int J Adhes Adhes, vol. 3 (1983), p. 85-91.
[15] J. R. J. Wingfield: Int J Adhes Adhes, vol. 13 (1993), p. 151-156.
[16] L. D. R. Grant, et al.: Int J Adhes Adhes, vol. 29 (2009), p. 535-542.
[17] Y. Zhang, *et al.*: Compos Struct, vol. 92 (2010), p. 1631-1639.
[18] R. D. Adams, *et al.*: Int J Adhes Adhes, vol. 12 (1992), p. 185-190.
[19] L. F. M. da Silva and R. D. Adams: Int J Adhes Adhes, vol. 27 (2007), p. 216-226.
[20] S. Ebnesajjad,in: Surface Treatment of Materials for Adhesion Bonding, William Andrew Publishing (2006).

Oil Palm Trunk Biocomposite: Mechanical and Morphological Properties

C. K. Abdullah[1*], M. Jawaid[2], H.P.S. Abdul Khalil[1], and M.R. Nurul Fazita[1]

[1]Division of Bioresource, Paper & Coating Technology, School of Industrial Technology, Universiti Sains Malaysia, 11800 Penang, Malaysia
[2]Department of Polymer Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 Johor, Malaysia
**ck_abdullah@yahoo.com*

ABSTRACT

In this research oil palm trunk biocomposites were produced by impregnating dried oil palm trunk with phenol formaldehyde resin. Peripheral region of oil palm trunk bottom parts were kiln dried until it attain 13%–15% moisture content, after that dried oil palm trunk impregnated with phenol formaldehyde resin by using high pressure vessel. In this study impact and compression properties of oil palm trunk biocomposites were studied. It observed that impregnation of oil palm trunk with phenol formaldeyde resin improves the impact and compression properties of oil palm trunk biocomposites.The oil palm trunk biocomposite with 60% resin loading showed better mechanical performance than other oil palm trunk biocomposites but still lower than rubberwood. Scanning electron microscope was used to study the surface morphology of oil palm trunk, and location of resin in the oil palm trunk biocomposites at different resin loading. The phenol formaldehyde resin showed better interaction in oil palm trunk impregnated with 60% resin loading and resin penetration still retain the original dried oil palm trunk structure.

Keywords: *oil palm trunk biocomposite; dried oil palm trunk; rubberwood; phenol formaldehyde*

INTRODUCTION

Oil palm plantations in Malaysia is close to 4.05 million hectares and during replanting process, it generates approximately 8.2 million tons of oil palm trunk (OPT). Constraint for the use of oil palm trunk as value added product making it a serious pollution problem in the field. Te OPT are normally left to rot or burnt in the field and this method is now unacceptable because it could affects the process of planting new crops [1,2]. The high density variation within the oil palm trunk has a significant effect on its strength properties. Based on study by Lim and Gan [3], the modulus of rupture (MOR) and modulus of elasticity (MOE) are found to be linearly correlated to the OPT density. Therefore, the selection of OPT to be value-added product need to consider the variability over the trunk, both radially and vertically.

Phenol Formaldehyde (PF) resins are the most important and common class of resin adhesives. The PF resin is the most frequently used and environmentally more acceptable because of negligible formaldehyde emission. PF resins tend to be the most widely used adhesives for bonding wood products due to the excellent adhesion to lignocellulosic, durable, provide high quality wood bonding and suitable for use under all climatic conditions [4]. However, conventional PF adhesives are slow curing, require higher curing temperature, and are less tolerant to variations in anatomical features and wood substrate. The role of the PF resin in the oil palm trunk is to transfer the load to the stiff fibers through shear stress at the interface. In addition, with the help of PF resin properties, the fiber will acts as obstacles to impede the crack propagation [5].

Studies on the enhancement of OPT characteristic to become high performance product in dimensional stability, durability, and strength has been done by Edi Suhaimi [6], Erwinsyah [2] and Bakar [7]. The thermal properties of OPT modification has been studied by Bhat et al. [1] and showed a great thermal and degradation stability. In the other hand, the biodeterioriation exposure of modified OPT with termite have been done by Edi Suhaimi [6] that exhibited better resistance properties compared to unmodified OPT. Oil palm trunk is largely composed of parenchymatous tissues with numerous fibrous strands and vascular bundles. The tough vascular bundles are scattered in soft parenchyma tissue. Toughening the oil palm trunk with PF resin is novel approach to produce a new type of palm lumber and as an alternative source for wood based industries.

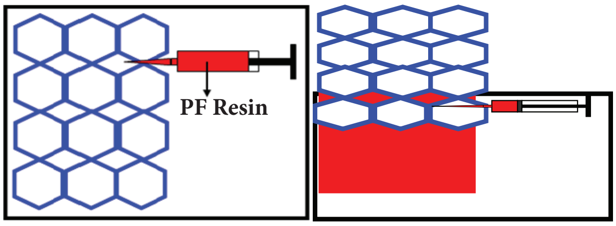
EXPERIMENTAL

Materials

The oil palm trunks at 25 years old were taken from KL-Kepong Berhad Plantation in Kulim, Kedah. Only bottom parts and outer region from oil palm trunk were chosen for drying and impregnation process. The phenol formaldehyde (PF) resin was obtained from Hexion Specialty Chemicals Sdn. Bhd

Preparation of Oil Palm Trunk Biocomposite (OPTB)

The outer parts of the OPT were cut into dimensions 1000 x 70 x 70 mm and later kiln dried for 20 days using kiln dried schedule IV to obtain approximately 13–15% of moisture content. The dried OPT was impregnated with PF with different resin loading (30%, 60%, and 90%) using a high-pressure vessel. The dried OPT were put in the pressure vessel for impregnation process at 5 bar pressure. Figure 1 (a) and (b) showed the schematic of impregnation process which occurs in oil palm trunk. The time of impregnation varied from 15 to 45 min for different percentages of resin loading. The oil palm trunk biocomposite (OPTB) impregnated with PF resins were cured for 2 hours in an oven at 150°C respectively.



(A) (B)

Figure 1: (a) The schematic drawing of dried oil palm trunk intercellular cavities structure, (b) PF resin penetrated into the oil palm trunk intercellular cavities structure.

Impact test

Impact tests were based on ASTM D256; Standard Test Method for determining the Izod Pendulum Impact Resistance of Plastics. Sample dimension for impact test is 60 × 20 × 12 mm. Sample was tested using charpy test. Before test is done, V-notch must be made on the sample. V-notch can be done using Gotech V-notch machine. Depth of V-notch is 2 mm and angle of V-notch is 90°. Weight of impact pendulum is 2.72 J and speed 3.46 m/s.

Compression test

Compression test is done with sample dimension of 60 × 20 × 20 mm according to BS EN 373: 1957. This test is conducted using Instron machine with speed of moveable head is 0.64 mm/min.

Scanning Electron Microscopy (SEM)

Scanning electron microscope (Leo Supra, 50 VP, Carl Ziess, SMT, Germany) from Unit of Microscope Electron, School of Biology, Universiti Sains Malaysia, Penang was used to analyze the morphological images of OPTB and dried OPT. A thin section of the sample was mounted on an aluminum stub using a conductive silver paint and was sputter-coated with gold prior to morphological examination. The SEM micrographs were obtained under conventional secondary electron imaging conditions with an acceleration voltage of 5 kV.

RESULT AND DISCUSIION

Impact Properties

Impact strength of OPTB with different resin loading, dried OPT and rubberwood were shown in Figure 2 at primary axis. The impact strength of OPTB increased with the increase in resin loading. However, after resin loading exceeds 60%, there was a considerable decrease in impact strength. Also, the impact strength of OPTB with 60% resin loading is comparable with rubberwood properties.

The enhancement of interfacial friction stress and chemical bonding between matrix and fiber may cause the strength to improve. Brown [8] obtained that extra energy was needed to be absorbed by composite in order to do the work of debonding between filler and matrix. Thus, the OPTB impact strength continued to increase at higher resin loading. Previous study by Seena et al. [9] suggested that the impact failure of the composite may be caused by matrix fracture, fiber/matrix debonding and fiber pull out. In this experiment, the extensive decrease of impact strength in case of OPTB with 90% resin loading was more related to the matrix fracture. The matrix fracture occurred, when the fiber and the resin were not bonded during curing process. This may be due to PF resin which not has proper interfacial adhesion between the fiber and matrix.

The impact properties were directly related to the overall toughness of the materials, which were highly influenced by the interfacial bond strength, matrix and fiber properties [10]. In case of 60% resin loading impact strength is due to greater impregnation of the resin within the pits or pores of the OPTB, thereby enhancing its impact properties. Furthermore, with the help of resin properties, the fiber acts as obstacles to impede the crack propagation. In order to move past the obstacles, more energy is needed to propagate the cracks and thus increase the impact strength [5,11].

Therefore, the impulsive forces applied during the impact test were being absorbed efficiently by the fibers of the OPTB [12]. The resin loading beyond 60% impart brittleness to the composite materials and thus the material cannot efficiently resist fracture under stress applied at high speed. This phenomenon also was due to its low strength nature, irregular cross–section and the presence of fiber bundles [13]. Besides, previous study by Lai [14], the increase of impact strength is attributed to the effective stress transfer between strongly adhered filler and matrix due to the physical and chemical bonding between them. Moreover the PF resin acts better stress transferring medium in OPTB.

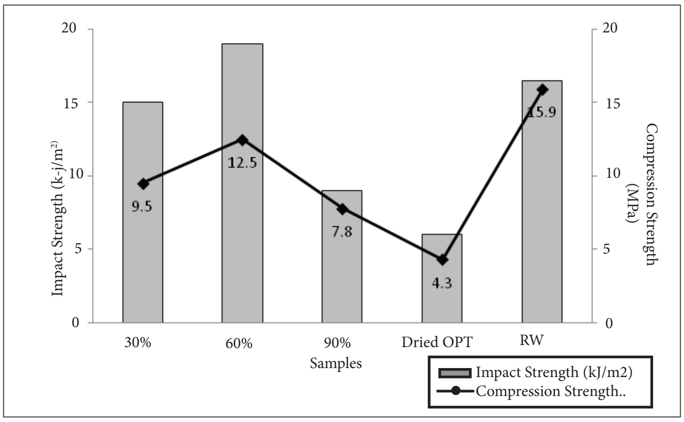


Figure 2: Impact Strength (primary axis) and compression strength (secondary axis) for OPTB with different PF resin loading compared to dried OPT and rubberwood.

Compression Properties

Compression strength of OPTB with different resin loading, dried OPT and rubberwood were displayed in Figure 2 at secondary axis. In general, OPTB with 60% of resin loading attained highest compression strength among the OPTB with 30% and 90% resin loading. However, like other mechanical properties, rubberwood again exhibited the highest compression strength as compared to OPTB. The effectiveness of PF resin in enhancing compressive properties showed a similar trend as flexural and impact properties. This result showed that, OPTB with 60% resin loading has capability to absorb more energy during stress, whereas the OPTB with 90% resin loading showed stiffer properties due to presence of excess resin.

The compressive strength of composite is strongly dependent on the effectiveness of the matrix in supporting the fibers against buckling. Also, research by John and Reid [15] reported that, epoxy matrix acted effectively as a stress transfer medium between fibers in the composite. While, low compression strength of dried OPT probably was due to high porosity. Starnes et al. [16] stated that, a gap or holes in the epoxy laminate enhanced the degradation of compression strength. This condition will be due to the inability of impregnated OPT to resist the break under compression stress Nevertheless, the presence of PF resin in OPTB structures is effective in resisting fiber buckling.

Scanning Electron Microscopy (SEM)

The morphological analysis of dried OPT and presence of PF resin in OPTB structures were carried out with the help of scanning electron microscope. The morphological detail about dried OPT structures, particularly vascular bundle was presented in Figure 3 (a).

The micrograph was obtained using SEM and from this picture, the existence of parenchymatous ground tissue, fibers, and vessels was easily recognized and identified.

Figure 3 (b) shows the damage of parenchyma tissues when 90% resin loading were force to be located in OPTB. The high pressure intakes during impregnation process, forced the resin to locate in parenchyma tissue and of vascular bundles. In resin penetration, optimum impregnation process is an important factor. In case of high force of resin penetration, the OPT structure may collapsed and hence giving poor mechanical locking. Besides that, the rupture of parenchyma tissue may occur due to reaction of moisture evaporation during the curing process. Recent study by Siimer et al. [17], reported that the resin cured on wood substrate is different as compared to the resin cured alone. When the resin overloaded in wood structure, the diffusion for moisture evaporation would not work as usual. This reason can be related with strength reduction in the mechanical properties of the IOPT with 90% rein loading.

Views of OPTB with 60% resin loading which incorporates within the parenchyma cell is shown in Figure 3 (c). The high porous morphology of dried oil palm trunk helps the resin to be located and filled within the space which will improve the characteristics of OPTB. After impregnation and curing process, PF resin were seen located in the parenchyma tissues. The parenchyma cells which are fully covered by PF resin were quite similar by attaining elongated shape. However, the PF resin only located in the parenchyma cells showed poor bonding.

The location and interaction of PF resin in OPTB with 30% resin loading as observed from the SEM is shown in Figure 3 (d). For the samples of OPTB with 30% resin loading, there are some spaces that are not filled by resin and the presence of these voids can lead to poor interaction between resin and OPT structure. Moreover, these voids may arise due to the inadequate amount of resin during impregnation process. During curing process, the evaporation of moisture creates the compound of solid content. The presence of less PF resin generate less solid content of PF resin which located in parenchyma tissues. Based on drying studies, when moisture released from OPT structures, shrinkage process will occur. This condition can be compared with OPTB 60% resin loading where the degree of parenchyma tissues shrinkage is less because of amount of PF resin located in OPTB structure. From the observation, it can be seen that, the extreme shrinkage of composite structure related to reduction of the matrix volume and generate weak interfacial bonding which will be affect the characteristic of composite [18].

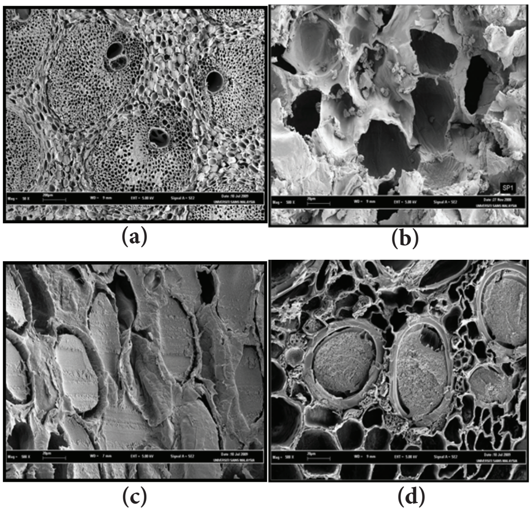


Figure 3: Scanning electron micrograph (SEM): (a) dried oil palm trunk (50x magnification), (b) OPTB with 90% PF resin loading (500x), (c) OPTB with 60% PF resin loading (500x), (d) OPTB with 30% PF resin loading (500x).

CONCLUSION

In this article, the dried OPT were impregnated using PF resin as a matrix to be a high performing products. The aim of this study was to characterize the mechanical and morphological properties of oil palm trunk biocomposite (OPTB). From our result, we conclude that usage of PF resin as matrix in the dried OPT improve properties of OPTB, such as impact and compression strength. After the testing, the OPTB with 60% resin loading have better mechanical properties than OPTB with 30% and 90% resin loading. The mechanical properties of OPTB showed more solidity on 60% resin loading and the strength decreased when the resin loading exceed 60%. The morphological analysis of the OPTB with 60% resin loading illustrated better allocation of resin in OPTB compared to OPTB with 30% and 90% resin loading.

ACKNOWLEDGMENTS

The researchers thanks to School Of Industrial Technology, Universiti Sains Malaysia, Penang, for providing the research facilities that have made this work possible.

REFERENCES

1. I. U. Bhat, C. K. Abdullah, H. P. S. Abdul Khalil, M. H. Ibrahim, and M. R. Nurul Fazita, Journal of Reinforced Plastics and Composites 29(22), (2010), p. 3301.
2. P. Erwinsyah, Dresden University of Technology: Dresden, Germany. Ph.D, (2008), p 443.
3. S. C. Lim and K. S. Gan , in Timber Technology Buletin, Forest Research Institute Malaysia: Selangor, Malaysia., 2005; pp 1-11.
4. L. Y. Tonge, J. Hodgkin, A. S. Blicblau, and P. J. Collins, Journal of Thermal Analysis and Calorimetry 64, (2), 721-730 (2001).
5. R. Kitey, and H. V. Tippur, Acta Materialia 53, (4), 1153-1165 (2005).
6. B. Edi Suhaimi, M. T. Paridah, F. Fauzi, S. Mohd Hamami, and W. C. Tang, in Proceedings of the 7th National Seminar on the Utilization of Oil Palm Tree, Malaysia: Oil Palm Tree Utilization Committee (OPTUC), Kuala Lumpur, 2007; pp 99-112.
7. E. S. Bakar, M. Y. Massijaya, L. L. Tobing, and A. Makmur, Indonesian Journal of Forest Products and Technology 11, (2), 13-20 (1999).
8. S. K. Brown, British Polymer Journal 12, (1), 24-30 (1980).
9. S. M. Seena J, Oommena Z, Koshyc P, Sabu T., Composites Science and Technology 62, (14), 1857-1868 (2002).
10. H. P. S. Abdul Khalil, H. D. Rozman. Gentian Dan Komposit Lignoselulosik. Penerbit Universiti Sains Malaysia. Penerbit Universiti Sains Malaysia: 2004.
11. J. Spanoudakis, and R. J. Young, Journal of Materials Science 19, (2), 473-486 (1984).
12. H. P. S. A. Khalil, M. S. Alwani, R. Ridzuan, H. Kamarudin, and A. Khairul, Polymer-Plastics Technology and Engineering 47, (3), 273-280 (2008).
13. M. S. Sreekala, J. George, M. G. Kumaran, and S. Thomas, Composites Science and Technology 62, (3), 339-353 (2002).
14. J. C. Lai, in, Universiti Teknologi Malaysia: 2007; Vol. MSc.
15. J. R. Lager, and R. R. June, Journal of Composite Materials 3, (Jan), 48-56 (1969).
16. J. H. Starnes, Rhodes, M.D. & Williams, J.G. , in Nondestructive Evaluation and Flaw Criticality For Composite Materials-STP 696 ed. Pipes, R. B., ASTM International: 1979; pp 145-169.
17. K. Siimer, T. Kaljuvee, P. Christjanson, and I. Lasn, Journal of Thermal Analysis and Calorimetry 84, (1), 71-77 (2006).
18. H. Kaddami, A. Dufresne, B. Khelifi, A. Bendahou, M. Taourirte, M. Raihane, N. Issartel, H. Sautereau, J.-F. Gérard, and N. Sami, Composites Part A: Applied Science and Manufacturing 37, (9), 1413-1422 (2006).