Insight into Lignocellulosic Biodegradation and Its Potential for Enzyme Production

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In 2006, Malaysia was the second largest producer of palm oil with 15.88 million tonnes or 43% of the total world supply. In 2007, there were 4.3 million hectares of productive oil palm plantations, a 3.4% increase from 4.2 million hectares in 2006 (1).

As palm oil production increased, there was a corresponding increase in the amount of residue generated. One hectare of oil palm plantation can produce about 50-70 tonnes of biomass residue. So the oil palm industry is currently the largest producer of biomass in the country. Of 70 million tonnes, about 17.4 million tonnes come from oil palm empty fruit bunch (OPEFB) fibre and 53.1 million tonnes from palm oil mill effluent (2).

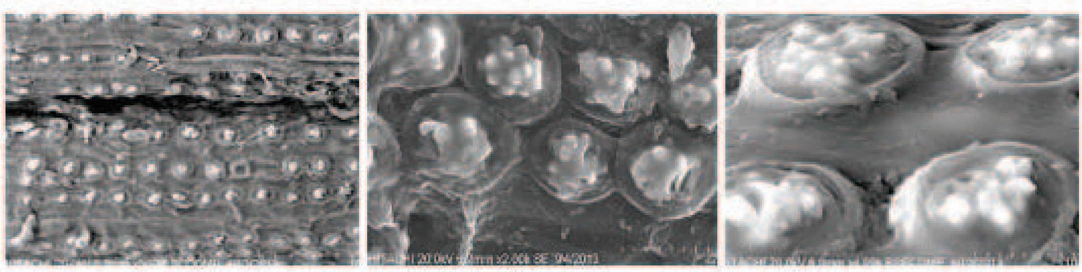
The use of OPEFB has been well explored in various industries such as biocompost(3), biosugar(4), bioethanol(5) and biogas(6). However, due to the presence of silica bodies on the surface of the OPEFB fibre, additional pre-treatment is required in order to obtain maximum usage of the OPEFB since the removal of the silica bodies would increase the porosity and breakage of the lignocellulosic material.

Silica bodies are in organic silica protrusions embedded in the surface of the OPEFB fibre. These are contained in their own craters and scattered randomly on the OPEFB fibre surface (Figure 1). Some researchers claimed that the presence of silica bodies contribute to the strength and rigidity of the OPEFB fibre(7). In this article, we observe the relationship of the silica bodies with OPEFB fibre, which includes the effect of silica body geometry, anisotrophy/orthotropy and debonding mechanism.

A stress-strain curve of OPEFB fibre is presented in Figure 2 where there are three regions observed during the analysis: Elastic region, plastic/debonding region and fracture region. In the first region, the bonding of silica bodies with fibre was tight and perfect while no failures or breakages were observed on the interface of the silica bodies. In the plastic/debonding region, the interface of the silica bodies started to debond, causing the curve to deviate from elastic line. In the final region, the debonding continued until complete failure or breakage was observed.

A 2D model development was performed using Abaqus software where the silica bodies were considered as filler and the OPEFB fibre as matrix. The effect of filler volume fractions (10%, 15% and 20%) was performed using the simulation of 10-spikes filler. A control of no spikes (circular filler) was also compared.

The results showed that the models with spikes were almost similar with the circular filler. The same result was also obtained for different volume fractions (Figure 3). The effect of the number of spikes (5, 10 and 20) on the silica bodies was also investigated, using the similar volume fraction of 15% (Figure 3). Due to the



(a) (b) (c)

Figure 1: SEM micrograph of silica bodies on EFB fibre under 500x magnification (a), 2000x magnification and 4000x magnification (c)

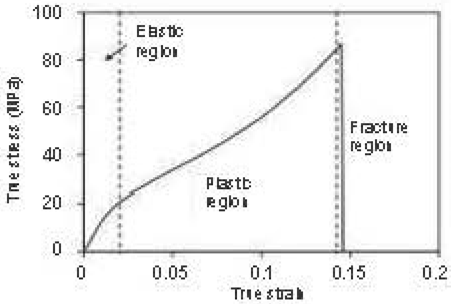


Figure 2: Stress strain curve of EFB fibre, indicating elastic, plastic and fracture region.

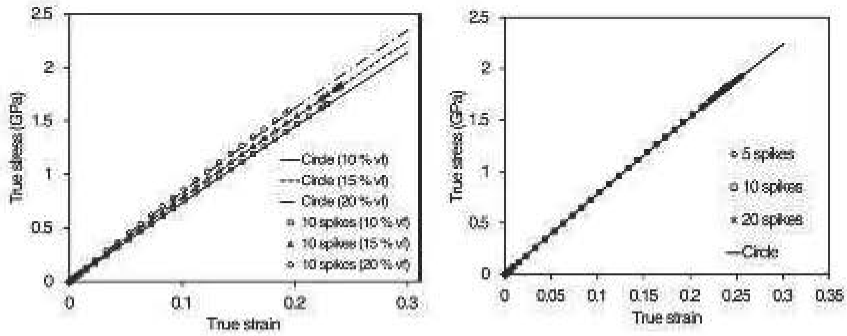


Figure 3: Effect of filler volume fraction under (left) uniaxial tension and (right) effect of number of spikes using volume fraction 15%

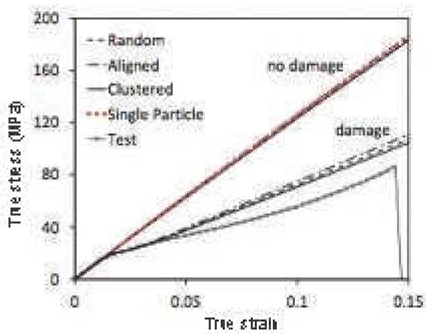


Figure 4: Modelling results of 2D models for aligned, random and clustered arrangements of silica bodies.

longitudinal arrangement of silica bodies along the fibre, there was a possibility of direction-dependant behaviour (anisotropy). The results showed that the 10-spikes models of anisotropy A (Ey = 3.235 GPa) and anisotropy B (Ey = 1.617 GPa) were not much different from the models with circular filler (no spikes).

The effect of silica bodies arrangement was also investigated in a 2D multi-particle model. The model consisted of 20 particles representing the inorganic silica bodies surrounded by the fibre as matrix.

There were three types of silica body arrangements – aligned, clustered and random. Using zone cohesive modelling (CZM), the debonding between the silica bodies and the fibre surface was investigated. Early termination (at 0.02 true strains) was observed in all models with damage, while all models without damage showed similar results with all types of arrangements (Figure 4).

This 2D model was also found to be more sensitive to critical stress than silica bodies spiked geometry, arrangement of silica bodies on the fibre surface and cohesive energy. Naturally, the silica bodies were found to be embedded halfway in the fibre surface. The damage of silica bodies at the cross-section of the fibre might be present.

A 3D development was developed to investigate the effect of silica bodies on elasticity and damage along the cross-section of the fibre. The difference in thickness of the fibre was investigated. The thickness of fibre/matrix was varied from 0.03 to 0.3 mm to observe the effect of fibre thickness on the elasticity of fibre-protrusion system.

The numerical results showed that the effect of silica bodies on the elasticity of the fibre was not significant when fibre thickness was more than 0.2 mm. Cell wall opening was later incorporated in the 3D model, where the thickness of the cell wall was set at 0.005 mm and the opening size was set at 0.02 mm. Both models showed similar results, indicating that different mechanisms of the fibre might be responsible for the plastic region of stress-strain curve in addition to the silica bodies and fibre interface damage.

The effect of silica bodies was also investigated in ligninolytic enzymes production where the OPEFB fibre was used as the substrate. A local isolated fungus was used in order to produce the ligninolytic enzymes from OPEFB fibre.

The OPEFB fibres used were both raw and chemically treated. The 10-day fermentation results showed that treated OPEFB was preferred by the lignin degrader to produce high ligninolytic enzymes. A 5-10% of the increment in the lignin peroxidase enzyme activity was observed. A similar observation was also found with manganese peroxidase and laccase production. This was mainly due to the removal of the silica bodies and a considerable amount of lignin was achieved in the treated OPEFB.

As mentioned by Shamsudin *S. et al.*, (8) the removal of silica bodies left hollow craters, exposing larger surface areas for the enzyme to digest the lignocelluloses materials. The same phenomenon was also found by Harun N.A.F *et al.*, (9). These silica bodies were present to prevent the fibre from microbial attack. The silica bodies and waxy layer on the outer surface of the fibre act together as an impermeable layer, preventing the fibre from being oxidised and hydrolysed by oxygen and microorganisms. ■

REFERENCES

[1] Shuit S.H., Tan K.T., Lee K.T., Kamaruddin A.H. (2009) Oil palm biomass as a sustainable energy source: A Malaysian case study. Energy 34: 1225–1235.

[2] Chun S.G, Kok T. T. and Keat T.L (2010) Bio-ethanol from lignocellulose: Status, perspectives and challenges in Malaysia. Bioresource Technology 101(13): 4834–4841.

[3] Wan Razali W.A., Baharuddin A.S., Talib A.T., Sulaiman A, Naim M.N., Hassan M.A. and Shirai Y. (2012) Degradation of oil palm empty fruit bunch (OPEFB) fibre during composting process using in vessel composter. Bioresources 7(4): 4786-4805.

[4] Abu Bakar N.K., Abd-Aziz S., Hassan M. A., Ghazali F.M. (2010) Isolation and selection of appropriate cellulolytic mixed microbial cultures for cellulases production from oil palm empty fruit bunches. Biotechnology 9:73-78.

[5] Minhee Y., Yule K., Youngran K., Bongwoon C., Gi-Wook C. (2011) Bioethanol production from optimized pretreatment of cassava stem. Korean Journal of Chemical Engineering. 28(1): 119-125.

[6] Nieves D.C., Karimia K., and Horavth I.S. (2011) Improvement of biogas production from oil palm empty fruit bunches (OPEFB). Industrial Crops and Products. 34(1): 1097-1101.

[7] Law K.N., Daud W.R.W., and Ghazali A. (2007) Morphology and chemical nature of fibre strands of oil palm empty fruit bunches (OPEFB). Bio Resources 2(3): 351-362.

[8] Shamsudin S., Md Shah U.K., Zainudin M.H, Abd-Aziz S., Mustapa Kamal S.M., Shirai Y., Hassan M.A. (2012) Effect of steam pretreatment on oil palm empty fruit bunches for production of sugars. Biomass and Bioenergy 36: 280-288.

[9] Harun N.A.F., Baharuddin A.S., Zainudin M.H.M., Bahrin E.K., Naim M.N., Zakaria R. (2013) Cellulase production from treated oil palm empty fruit bunch degradation by locally isolated Thermobifida fusca. Bio Resources. 8(1): 676-687.