16

Application of Thermoplastics in Protection of Natural Fibres

Fauziah Ahmad, Farshid Bateni,
Mohammadreza Samadi Tavana and Ahmad Shukri Yahaya
Universiti Sains Malaysia
Malaysia

1. Introduction

Nowadays thermoplastics are widely used in industries; many products used different specifications of the thermoplastics that are adapted to their requirement. The importance of consideration to the environmental protection leads the mankind to thinking about producing environment-friendly material, and also controlling the waste material by recycling or reducing them. In the meantime the natural materials such as cellulose based material are one of the major resources that can be used to replace with many manufactured materials. However, cellulosed based material such as natural fibres, because of their degradability, need protection from any circumferential agents. The protection may require a special condition in order to utilise in soil, due to water absorption, soil organisms, and minerals. Natural fibres are amenable to modifications as they bear hydroxyl groups from cellulose and lignin. In addition coating the fibres with any chemical materials reduce their water absorptions and protect them from any bacteria and fungi attack. The hydroxyl groups may be involved in the hydrogen bonding within the cellulose molecules. This weakness of the natural material and good characteristics of natural fibres is the basis of bio-composites invention.

Fibres	Cellulose (%)	Hemicelluloses (%)	Lignin (%)	Tensile Strength (%)	Elongation (%)	Toughness (MPa)
OPEFB*	65	-	19	248	14	2,000
Coir	32-43	0.15-0.25	40-45	140	25.0	3,200
Banana	63-64	19	5	540	3.0	816
Sisal	66-72	12	10-14	580	4.3	1,250
Pineapple	81.5	-	12.7	640	2.4	970

*OPEFB : Oil Palm Empty Fruit Bunch

Table 1. Chemical and mechanical properties of some important natural fibres

2. Natural fibres

Many different kinds of natural cellulosic fibre such as cotton, hemp, sisal, coconut fibres and oil palm fibres are used in different composite products. Properties of the natural fibres depend mostly on the nature of the plant, locality in which it is grown, age of the plant, and the extraction method that is used (Sreekala et al., 1997). Coir is a hard and tough multi cellular fibre with a central portion called ''lacuna.'', On the other hand, banana fibre is weak and cylindrical in shape. Sisal is an important leaf fibre and is strong. Pineapple leaf fibre is soft and has high cellulose content. Many studies have been done on the natural fibre based composite products (Maldas & Kokta, 1990; Pavithran et al., 1987; Shah & Lakkad, 1981; Sreekala et al., 1997). Table 1 summarised the chemical and mechanical properties of some natural fibres.

2.1 Properties of oil palm fibres

Oil palm is one of the most economical and very high-potential perennial oil crops. It belongs to the species of Elaeis guineensis under the family Palmacea, and originated in the tropical forests of West Africa. Major industrial cultivation is in Southeast Asian countries such as Malaysia and Indonesia. Large-scale cultivation has come up in Latin America. In India, oil palm cultivation is coming up on a large-scale basis with a view to attaining self sufficiency in oil production.

Oil palm fibre is non-hazardous biodegradable material, extracted from oil palm's empty fruit bunch (EFB). Oil palm fibre is an important lignocellulosic raw material. OPEFB fibre and oil palm mesocarp fibre are two types of fibrous materials left in the palm-oil mill. The mesocarp fibres are left as a waste material after the oil extraction. These fibres must be cleaned of oily and dirty materials. The only current uses of this highly cellulosic material are as boiler fuel and in the preparation of potassium fertilizers. When left on the plantation floor, these waste materials create great environmental problems. Therefore, economic utilization of these fibres will be beneficial (Sreekala et al., 1997).

Chemical constituents (%)	
Cellulose	65
Hemi cellulose	-
Lignin	19
Ash content	2

Table 2. Chemical constituents of oil palm empty fruit bunch fibre

Physical properties of oil palm fibre	
Diameter (mm)	0.15-0.50
Density (g/mm^3)	0.7-1.55
Linear density (denier)*	2150
Tensile strength (MPa)	100-400
Young's modulus (MPa)	1000-9000
Elongation at break (%)	14
Microfibrillar angle (°)	46

* 1 denier= 1/9000 g/m

Table 3. Physical and mechanical properties of oil palm empty fruit bunch fibre

OPEFB fibre is obtained after the subtraction of oil seeds from fruit bunch for oil extraction. OPEFB fibre is extracted by the retting process of the EFB. Average yield of OPEFB fibre is about 400 g per bunch. Previous studies report the mechanical properties of OPEFB fibres. Table 2 and Table 3 show the summary of oil palm fibre properties (Jacob et al., 2004; Sreekala et al., 2001; Sreekala et al., 1997)

3. Thermoplastic coat

Thermoplastics as a coating can lead to improving the natural fibre performance in two ways: 1. the thermoplastics cover the fibres and keep the fibres from any fungi or bacteria attacks by decreasing the water absorption and contact of the fibres to the soil and any organism inside it, 2. The physical performance of the fibre such as tensile strength and elongation can be affected by modification and coating with any kind of thermoplastics. Therefore, a method was developed to coat the fibres with the thermoplastics. The solvent was used to prepare soluble thermoplastic since the natural fibres cannot reside in high temperature. Different density of the thermoplastic solution was used to evaluate the coated fibres to reach the best strength and resistance. Two types of the fibre were used as a reinforcement of composites such as soil, first the discrete fibres where it needs to be coated one by one, and second is the sheet fibres that were made by compaction of bulk fibres. The fibre was coated by acrylonitrile butadiene styrene (ABS) solution and the characterisation test results for both single and sheet fibres are described in the following sections.

3.1 Acrylonitrile butadiene styrene

ABS is an important engineering copolymer widely used in industry due to superior mechanical properties, chemical resistance, ease of processing and recyclability (Yang et al., 2004). ABS is a common thermoplastic used to make polymeric wood composites, has good physical properties in comparison with other commodity plastics and is cheap in comparison with other engineering plastics (Huang & Mo, 2002).

ABS is derived from acrylonitrile, butadiene, and styrene. The chemical structure of the ABS is shown in Figure 1. Acrylonitrile is a synthetic monomer produced from propylene and ammonia. Butadiene is a petroleum hydrocarbon obtained from butane. Styrene monomers, derived from coal, are commercially obtained from benzene and ethylene from coal. The advantage of ABS is that this material combines the strength and rigidity of the acrylonitrile and styrene polymers with the toughness of the polybutadiene rubber. The most amazing mechanical properties of ABS are resistance and toughness.

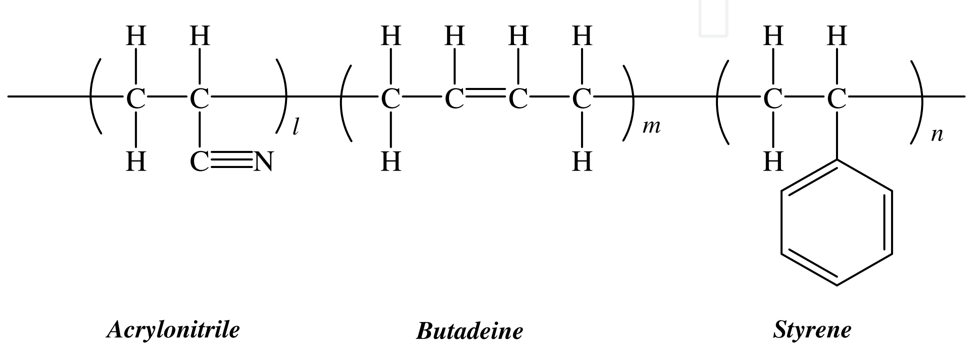


Fig. 1. Chemical structure of ABS

The chemical resistance for ABS is relatively good and it is not affected by water, non organic salts, acids and basic. The material will dissolve in aldehyde, ketone, ester and some chlorinated hydrocarbons. The properties of moulded ABS are shown in Table 4 based on MatWeb (2009) material specification data sheet.

Property	Test Method	Value
Tensile Strength	ASTM D638	44.8 MPa
Flexural Modulus	ASTM D638	2.59 GPa
Tensile Elongation	ASTM D638	15 %
Flexural Yield Strength	ASTM D790	69 MPa
Flexural Modulus	ASTM D790	2.59 GPa

Table 4. Physical properties of moulded ABS

3.2 Characterization of coated fibres

An ABS solution was prepared by adding ABS pieces to methyl ethyl ketone (MEK) solvent. Fibres were chopped into 30 mm length for water absorption tests and 100 mm length for tensile strength tests. The average aspect ratio for 100 mm length fibre was found to be equal to 250. The chopped OPEFB fibres were incubated in the 15% ABS solution to be coated. Coated fibres were dried over a mesh at room temperature.

3.2.1 FTIR

The chemical reactions during fibre coating were characterised using IR spectroscopy. IR spectra of the uncoated and coated OPEFB fibres are given in Figure 2 (Bateni et al., 2011). Series (a) is the IR spectra for ABS, Series (b) shows the IR spectra of OPEFB fibre and series (c) and (d) show the coated OPEFB fibre infrared spectra, for coating incubation times of 6 hour and 24 hour, respectively. ABS coating imparts physical and chemical modifications to the fibre. A band shown in the 3300–3600 cm^{-1} regions in coated and uncoated OPEFB fibre corresponds to O–H stretching of the cellulose and lignin. The intensity of the 1636 cm^{-1} band increased and the 3400 cm^{-1} band was shifted to 3420 cm^{-1}, corresponding to C=O stretching and O–H stretching vibrations after coating of the fibre, respectively. Strong peaks are observed in the IR spectrum of coated fibres at 2239 and 2929 cm^{-1} when compared with the uncoated fibre. Peak detected at 1455 cm^{-1} may correspond to the characteristic peaks of ABS plastic which are the aliphatic C–H stretching (Sreekala et al., 2000).

The presence of a peak at 2929 cm^{-1} may be due to C–H stretching. The peaks at 1039 and 2929 cm^{-1} for coated fibres were increased and shifted, corresponding to C–O stretching and C–H stretching vibrations. The change C=C peak frequency increased with coating. Two peaks were observed at approximately 2347 cm^{-1} due to C≡N stretching. The shifting of the 2347 cm^{-1} band to 2239 cm^{-1} indicates the change in C≡N stretching of the OPEFB fibre after coating by ABS. Those peaks which changed over the time show the increment the presence rate of ABS in coated fibres. The presence of the peaks over the time increment shows that the chemical reactions of ABS and fibres have increases. This increase led to a more physical stability of ABS coating over fibres and thus fibres were more resistant.

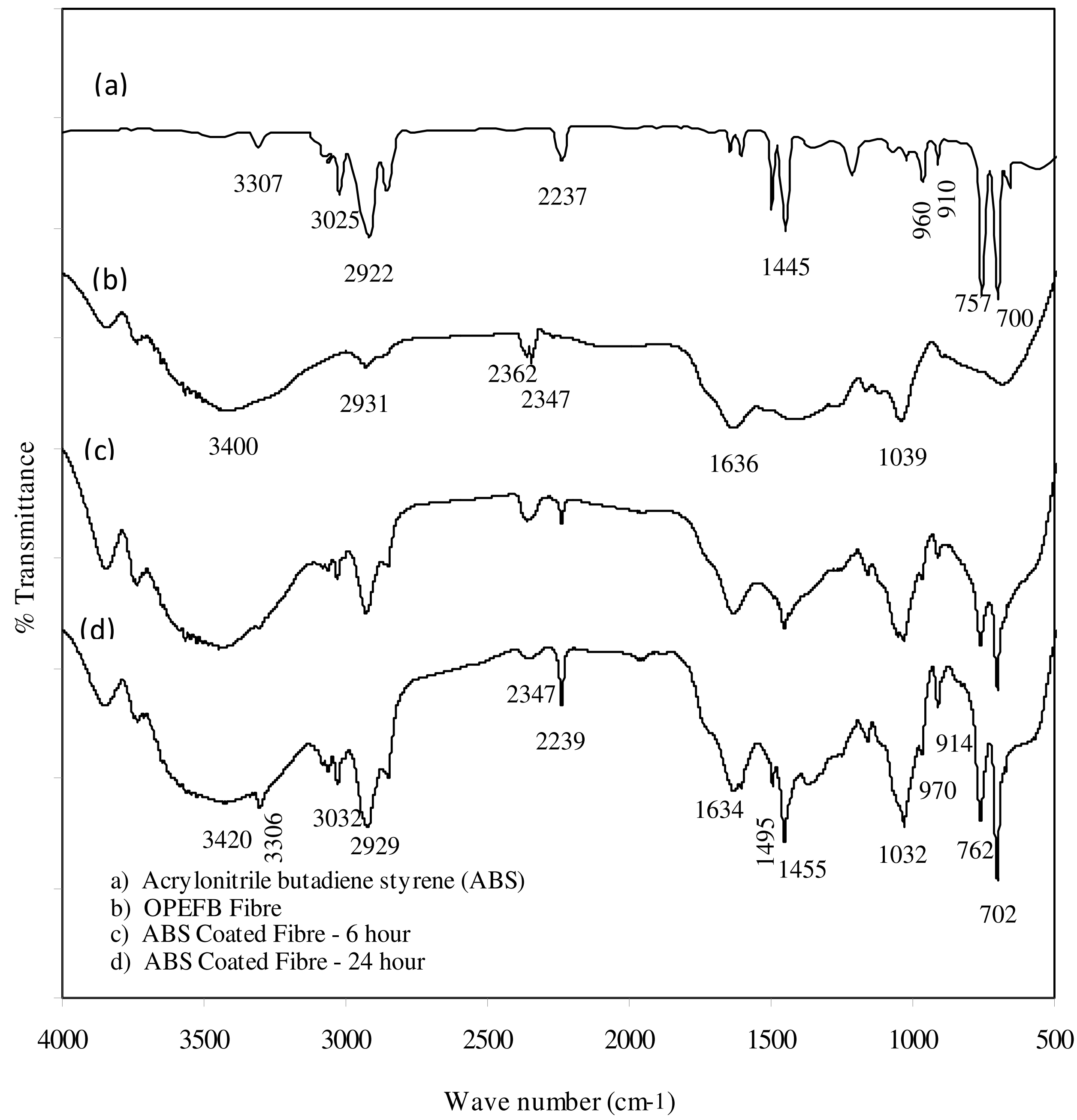


Fig. 2. FTIR of ABS coated and uncoated fibres

3.2.2 Fibre surface topology

The porous surface morphology was useful for better mechanical interlock of fibre with the ABS coating. The SEM micrograph of fibres and the coated fibres clearly shows the surface structure of an uncoated OPEFB fibre and the quality of thermoplastic coat (Figure 3). The micrographs show porous and grooves on the surface of the fibre. The uniform cover and fully coating of the fibre surface is an important factor in protecting the fibres while surface structure of a coated fibre is shown in Figure 3(b). The layer of ABS worked as a surface to protect the fibres from water, degradation and physical damages. The entire fibre appears to be covered and the surface exhibits a smoother surface than the uncoated fibre.

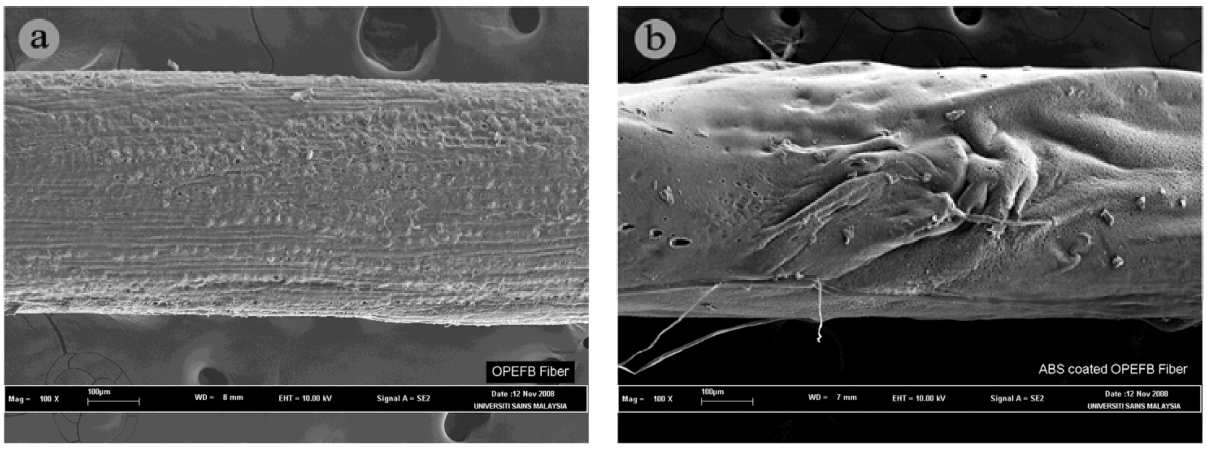


Fig. 3. SEM micrographs of uncoated (left) and coated (right) OPEFB fibre

Figure 4(a) presents the cross section of an uncoated fibre, which exhibits a lacuna-like portion in the middle in comparison with Figure 4(b), the SEM micrograph of the cross-section of a coated fibre. The thickness of the coated layer can be seen in the figure, the structure of portions is indicating the penetration of the ABS into the fibre structure. The ABS filled some of the lacuna like portion in the fibre.

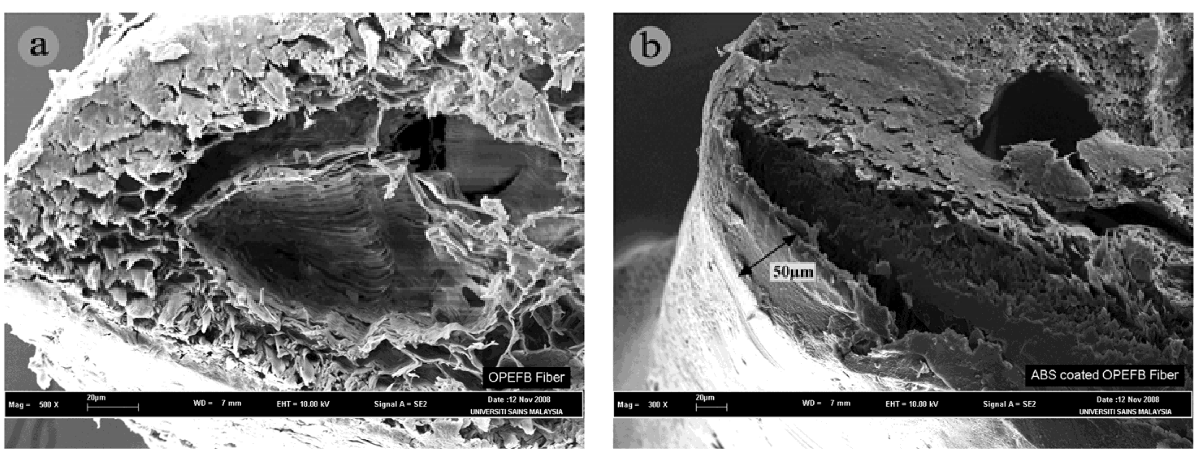


Fig. 4. Cross section of uncoated (left) and coated (right) OPEFB fibre

The uncoated fibre surface was found to be rough and had protruding portions and groove-like structures on its surface (Figure 5(a)). The surface of the coated fibre has an uneven structure, as shown in Figure 5(b). This feature of surface depends on the application of the fibres where it can be positive or negative due to less friction existence within the fibres and composites mass. Otherwise, the ABS coating may increase the diameter and the section area of fibres which can affect the contact surface area between fibres and soil particles. The surface area of the fibres is the most effective parameter in increasing the shear strength of some fibre reinforced composites.

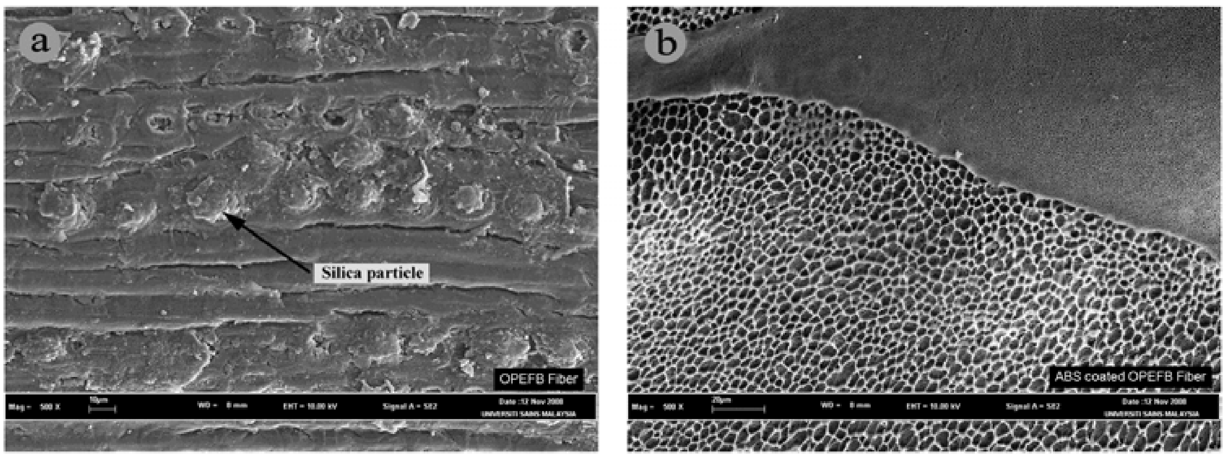


Fig. 5. Surface structure of uncoated (left) and coated (right) OPEFB fibre

3.2.3 Tensile strength of fibre

The tensile strength test result of the coated OPEFB fibre showed an increase in tensile strength of the fibre in breaking point. The elongation of the fibre in tensile test was increased from 15% to near 20% in coated fibre. The main improvement in coated fibres occurs in Young's modulus. Table 5 shows the tensile properties of coated and uncoated OPEFB fibre.

Type of the fibres	Tensile Strength (MPa)	Elongation at Break (%)	Young's modulus (MPa)
OPEFB fibre	283	15.4	5500
Coated OPEFB fibre	306	19.1	6600

Table 5. Summary of the tensile test result on coated and uncoated OPEFB fibre

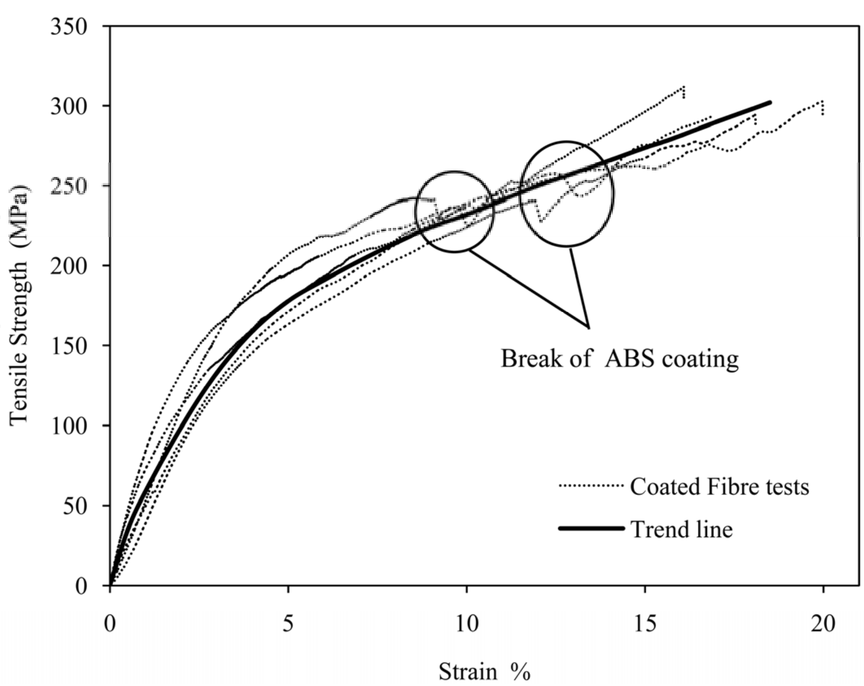


Fig. 6. Stress-strain curve of coated OPEFB fibres on tensile test

The tensile test result showed that the ABS coat was broken before failure of the OPEFB fibre, the gaps in the stress strain curve within the strain of 10% to 15% in Figure 6 describe the weakness of the coated fibres to handle the force. Figure 7 shows the photographs of the coated fibre before and after the tensile test. The split of the ABS coating was shown clearly at different strain of OPEFB fibre and ABS thermoplastic. From the figure the gap in the stress strain curve represented the failure of the ABS coat before the OPEFB fibres. The strain of the ABS thermoplastic (Table 3) also proves this result.

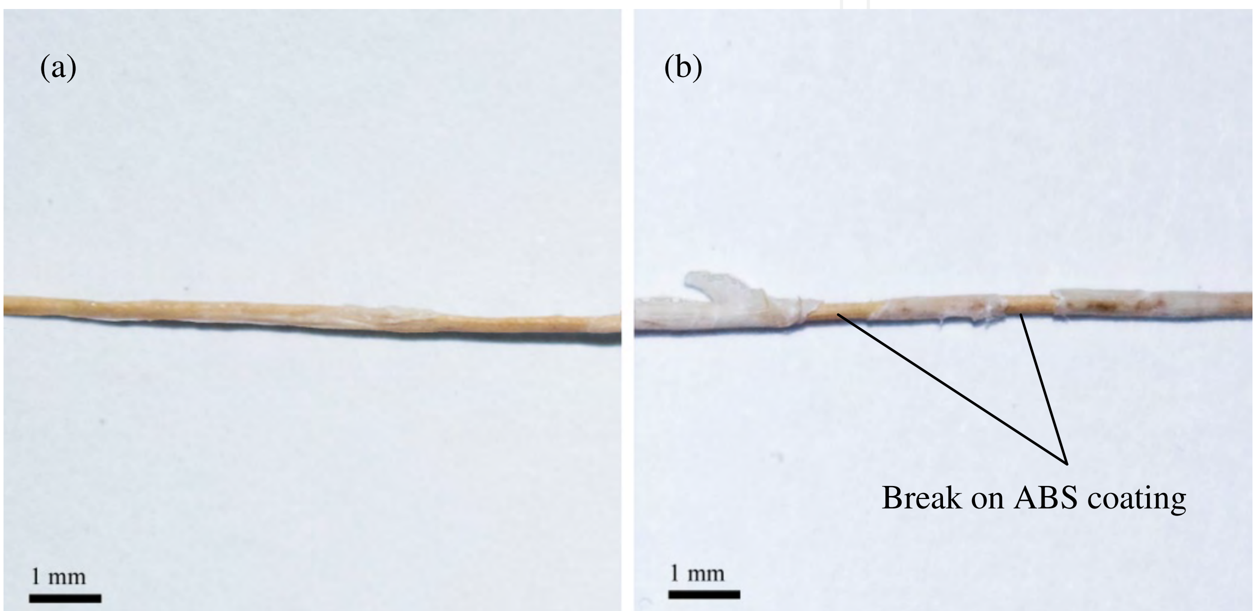


Fig. 7. Coated OPEFB fibre before and after tensile test, a) coated OPEFB fibre, b) Break of the coating after tensile test

3.2.4 Water absorption of fibres

The water absorption of the coated and uncoated OPEFB fibre was presented in Figure 8 as a percentage of dry weight. Figure 8 shows the absorption behaviour of coated and uncoated OPEFB fibre in distilled water at 30°C and 70°C respectively. The results show that the water absorption of the coated fibre was lower than that of the uncoated fibre. As the temperatures increased, the water sorption was generally decreased.

The decrease in sorption value for coated fibre had the same range of treated fibres with different methods reported by Sreekala & Thomas, (2003). Different fibre surface modifications such as mercerization, latex coating, gamma irradiation, silane treatment, isocyanate treatment, acetylation and peroxide treatment were used in their study. It is recommended that the modification techniques were also used before the coating process. The decrease of the water sorption capacity of the fibre reduces the biodegradability of the OPEFB fibre, and also increase in tensile capacity of the fibres.

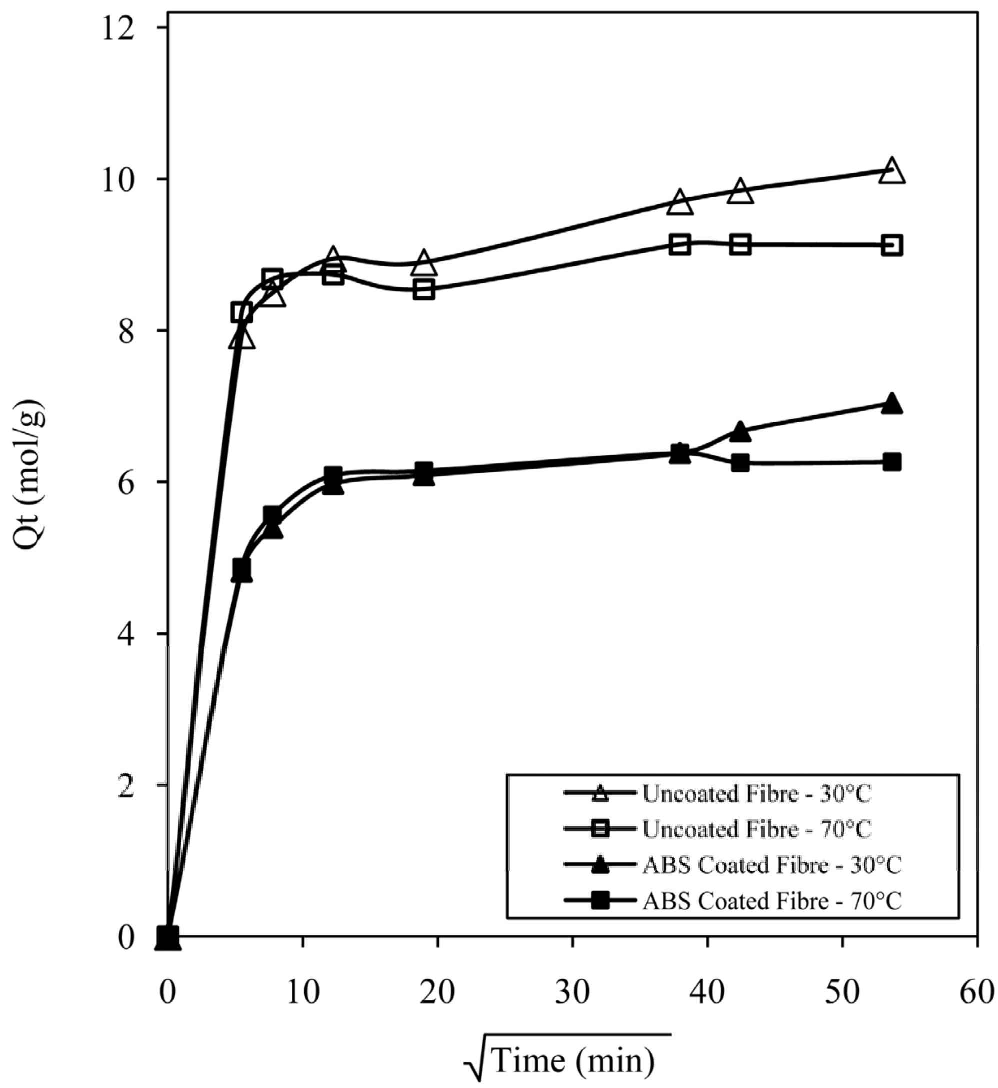


Fig. 8. Sorption curves of uncoated and ABS coated OPEFB fibres

3.3 Characterization of coated fibre sheets

For the first phase of experiments, the ABS solution was prepared in three different percentages of 5, 10 and 15 per cents. The 20% ABS solution was excluded from the experiments since some gel-forming behaviour was observed. The specimens were soaked for one minute in 5%, 10% and 15% of ANS solution and the tensile test conducted for specimens according to ASTM D4595-86 (2001) specifications. The 15% solution was picked for the rest of the experiments because it gives the optimum results. For next stage, the specimens were soaked in 15% ABS solution and repeated the tensile tests to study the effect of soaking duration on tensile strength.

3.3.1 Fibre sheets

OPEFB sheets are commercially available is Malaysia. These sheets are manufactured through a compaction process in which the fibres orient randomly (Figure 9). Sheets are produced only in single direction that is the machine direction, so there is no warp or weft direction, the detailed sheet and cross section are presented in Figure 9 and Figure 10.

The size of merchandised sheets was 3000 mm in length, 1000 mm in width and 10 mm in thickness. The coated or uncoated sheets have a potential to be used as a kind of geotextile for soil reinforcement was named Geo-Mat.

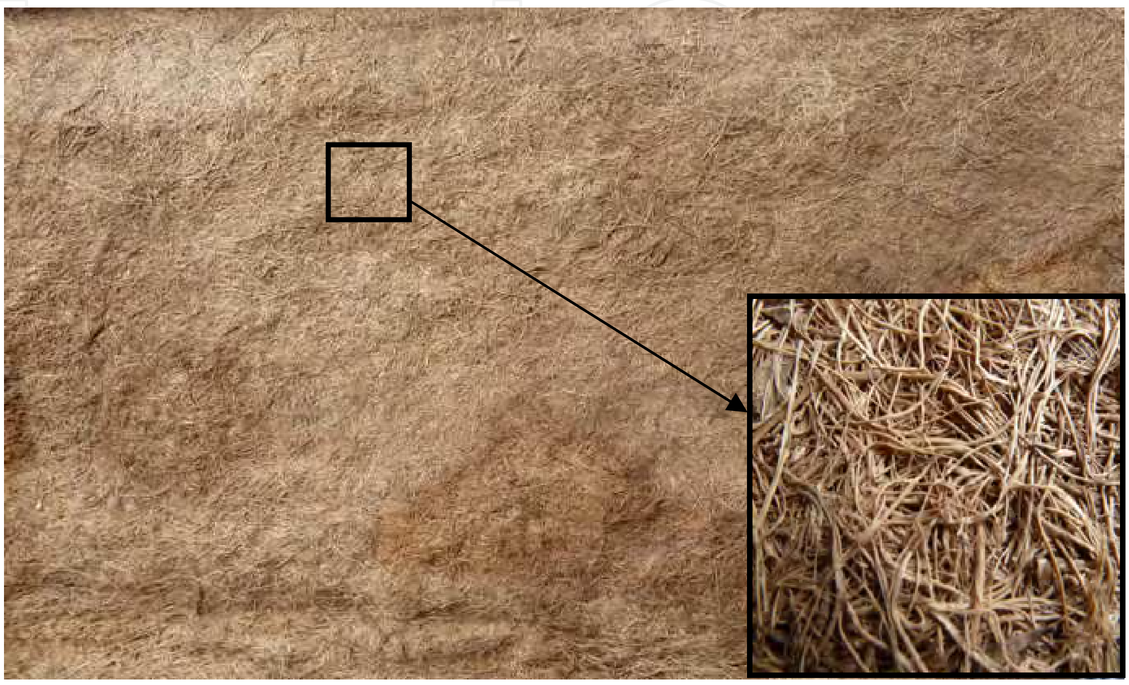


Fig. 9. OPEFB sheet

Fig. 10. Longitudinal cross section of OPEFB sheet

3.3.2 Effects of ABS percentage on OPEFB sheets

The weight variations of sheets are determined before coating and after drying process. The results, which are shown in Figure 11, showed that by increasing the density of ABS solution, larger amounts of ABS were oriented on the fibres.

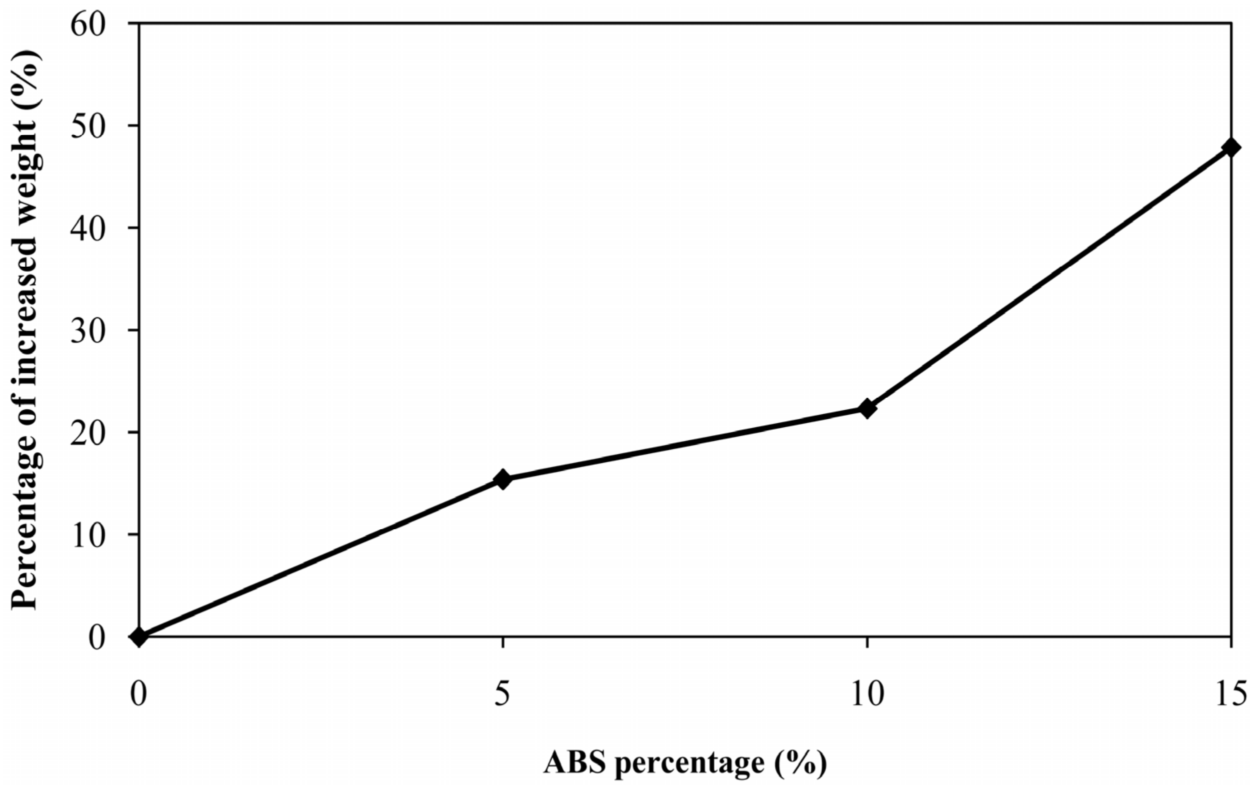


Fig. 11. Weight changes of ABS coated OPEFB sheets

The ABS thermoplastic brings ductility and toughness for the sheets. When the amount of oriented ABS increases, the toughness and ductility of sheets increases too. The influences of such ductility and toughness could become clearer by conducting the tensile test.

3.3.3 Effect of ABS percentage on tensile strength

By comparing the results of untreated sheets and 5%, 10% and 15% ABS coated sheets, it could be realized that the coating resulted to a slight increase in average tensile strength and remarkable decrease of elongation percentages. The effect of those variations is more obvious in tensile modulus, since it was doubled for the coated OPEFB sheets. Enhancement of 15% ABS coating showed better improvements than the 5% and 10% ABS coating; the average tensile strength of sheets reached to approximately 12 kN/m. The obtained average tensile strength is relatively 6 times higher than the average tensile strength of untreated OPEFB sheets. The resulted average tensile modulus of these sheets was around 350.3 kN/m. As it was expected, the ABS improved the tensile properties of OPEFB sheets very significantly. The ductility and toughness of 15% ABS coated sheets were more sensible than the others (Table 6). The ABS covered approximately all of the fibres properly and filled the void areas among the fibres.

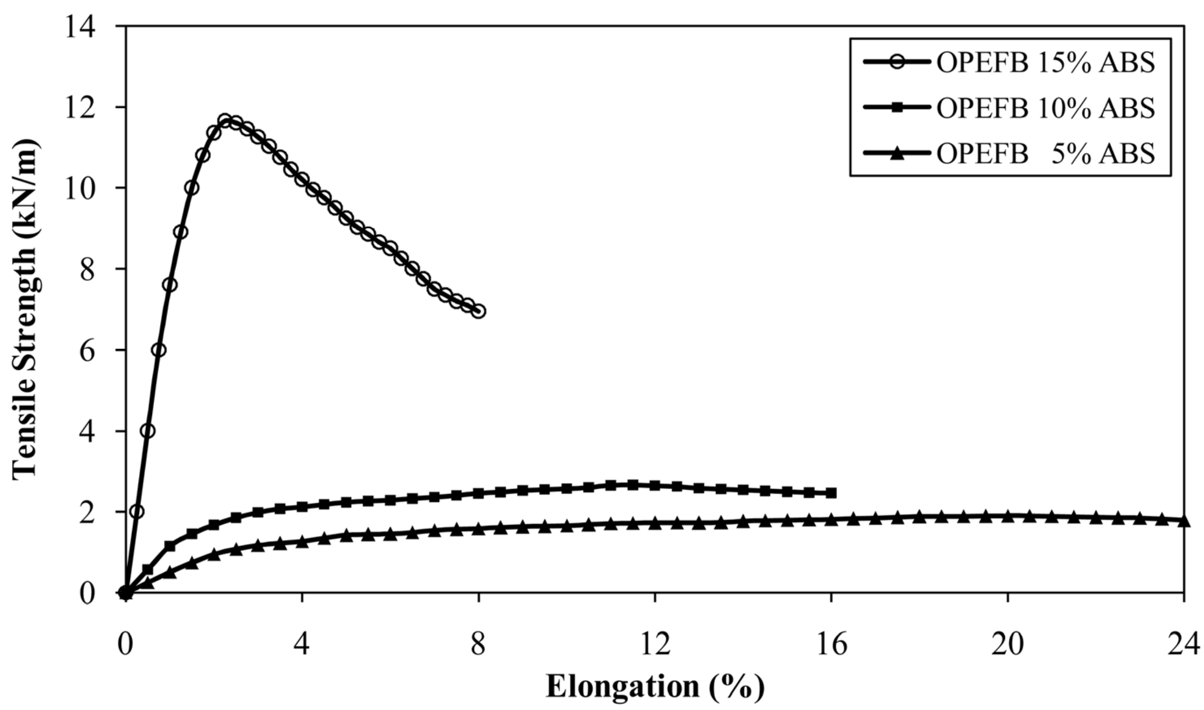


Fig. 12. Comparison of tensile test results for 5%, 10% and 15% ABS coated OPEFB sheets

Since the 15% ABS solution covered the fibres and sheets more properly, it is expectable to experience higher tensile strength and also better durability for them. It is worth to mention that for all specimens, the complete rupture did not occur at the peak force. Although the failure area became clear, but the two parts of sheets were still joined together. The Figure 13 shows the rupture area of the failed specimens of ABS coated sheets.

Specimen	Breaking Force (kN)	Tensile Strength (kN/m)	Elongation (%)	Tensile Modulus (kN/m)
Uncoated	0.359	1.79	37.08	4.80
5 %	0.392	1.93	20.60	9.37
10 %	0.542	2.71	12.27	22.00
15 %	2.41	12.05	3.44	350.30

Table 6. Tensile properties of ABS coated OPEFB sheets

3.3.4 Tensile strength comparison

Among the previous works there is only one work which is comparable. Subaida et al. (2008) conducted experimental investigation on tensile strength of woven coir geotextiles. They reported that the tensile strength of the mesh mattings lies in range of 10 and 20 kN/m. The tensile test was carried out for three types of nonwoven geotextiles with commercial names of MTS 300, MTS 350 and MTS 400. MTS series geotextiles are a technical fabric mechanically bonded nonwoven needle punched made from 100% UV stabilized polyester. The average tensile test results of these fabrics are presented and compared by Figure 14. For all of these fabrics the peak tensile strengths are achieved at relatively large values of elongation which are practically useless. In soil structures large displacements are equal to failure of structures; basically, soil reinforcing materials must be able to reach to the peak tensile strength within the minimum displacement. Between all the materials mentioned in Figure 14, the 15% ABS coated OPEFB sheets are the most suitable choice based on the highest tensile strength along with the small elongation at the peak point.

Fig. 13. Rupture area for 5% ABS coated OPEFB sheet

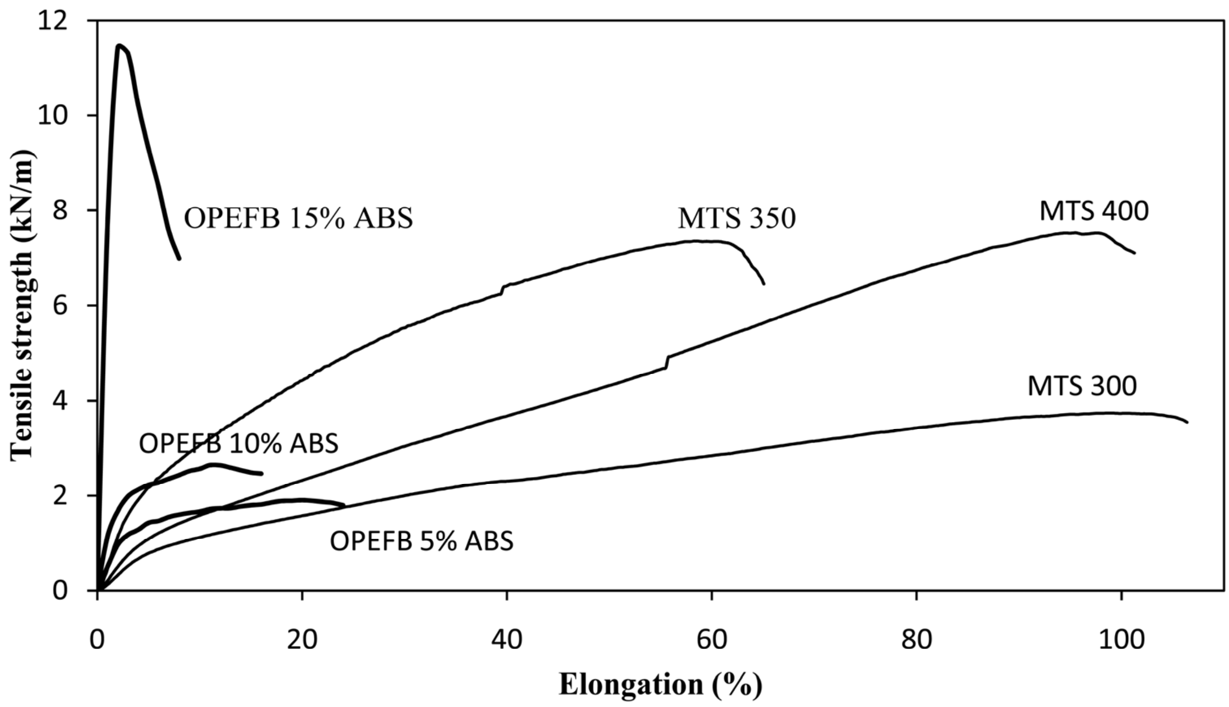


Fig. 14. Tensile test result of MTS fabrics and coated OPEFB sheets

3.3.5 Biodegradation of fibres

The degradable properties of both coated and uncoated OPEFB fibre were monitored through aging in two different soils and in contact with moisture and fungus for about 3 months. Figure 15 shows the effect of fungus in the degradation of the fibre, the black part of the fibre was affected by the fungus. Most part of the uncoated fibres was influenced by fungus and the fungus spread over the surface of the fibres. In comparison the coated fibre was less affected by fungus and it only decayed at the end parts of fibres. Otherwise, the colour of the fibres was shown as the water sorption in the uncoated fibres. Water is the important factor for the growth of the fungus that increased the biodegradation of the fibres.

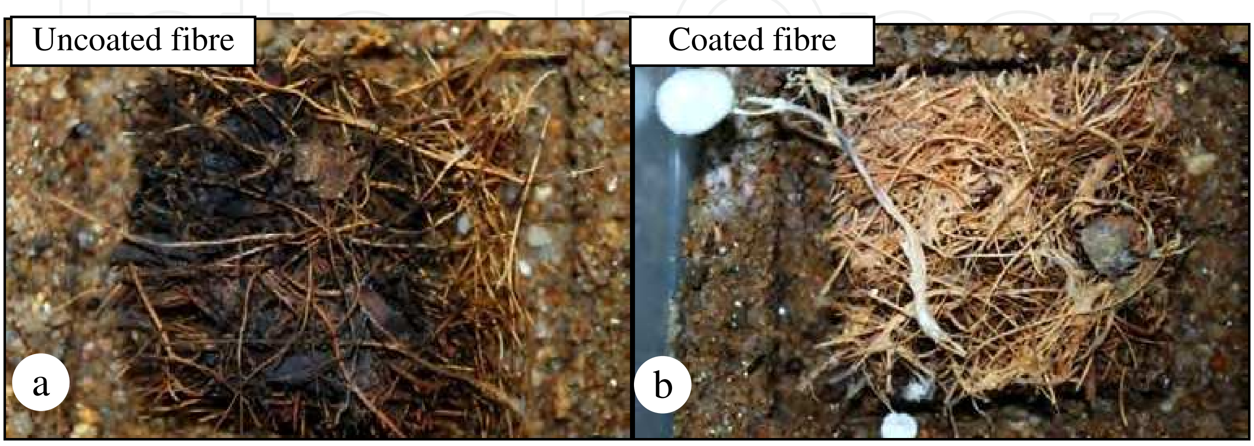


Fig. 15. Fungus biodegradation of the fibres after 3 month a) Sheet of OPEFB fibre, b) Sheet of coated OPEFB fibre

The fibres were also placed in to the silty sand and peat soil to estimate the weight loss of the fibres in soil. The discrete fibre and fibre sheet were weighed before test. The fibres also were coated with ABS solution for 24 hours and all the specimens were placed on soils for about 3 months.

Figure 16 shows the coated and uncoated OPEFB fibre after aging in the silty sand soil. The fibre sheets decayed after 3 months and it is shown that the uncoated fibre had the separate structure due to the biodegradation of the fibre.The coating was protected the fibres from biodegradation; the shape of the coating fibres was kept.

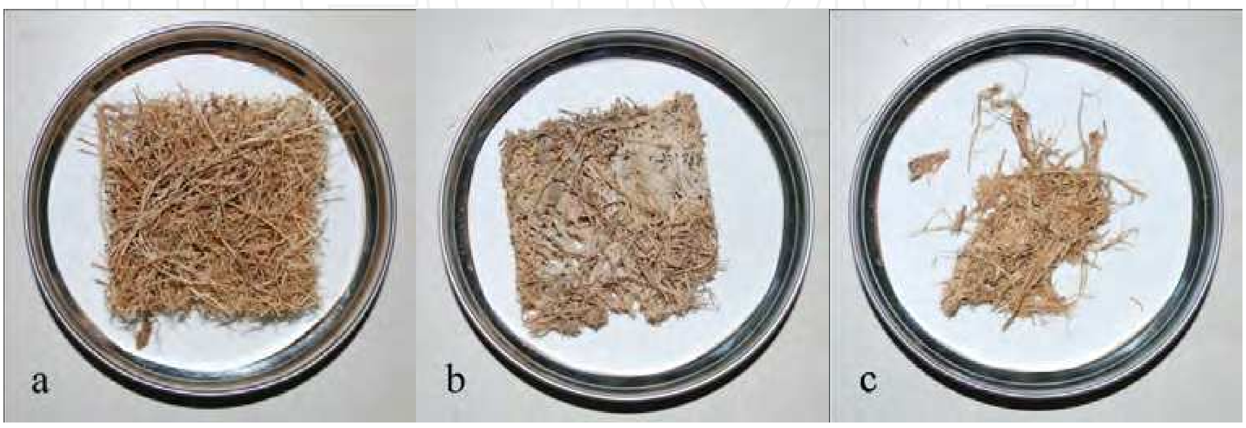


Fig. 16. a) before decay b) decayed ABS coated c) decayed uncoated fibre sheet in the silty sand soil after 3 months

The same results are shown in Figure 17 for the fibres in organic clay soil. The uncoated sheet fibre in organic clay separated from each other and did not have the textile structure. The uncoated fibre lost its weight due to biodegradation in the soil.

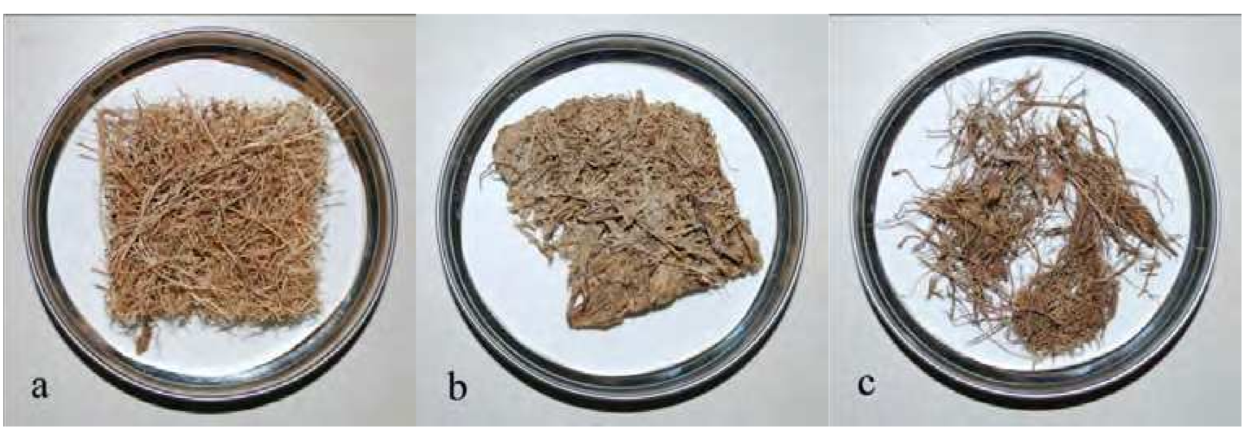


Fig. 17. a) before decay b) decayed ABS coated c) decayed uncoated fibre sheet in the organic clay soil after 3 months

The results of these losses are graphically plotted in Figure 18. Loss of weight of the discrete fibres was higher than the fibre sheet due to their larger contact surface with the soils and environment factors.

The result shows that in all condition coating decreases the biodegradation of the fibres both in discrete fibre and fibre sheet. The decay of the fibres in three conditions had approximately the same result. The weight loss result indicate the influence of coating on protecting OPEFB fibres from biodegradation, around 50% decrease on weight loss were estimated from tests after three months.

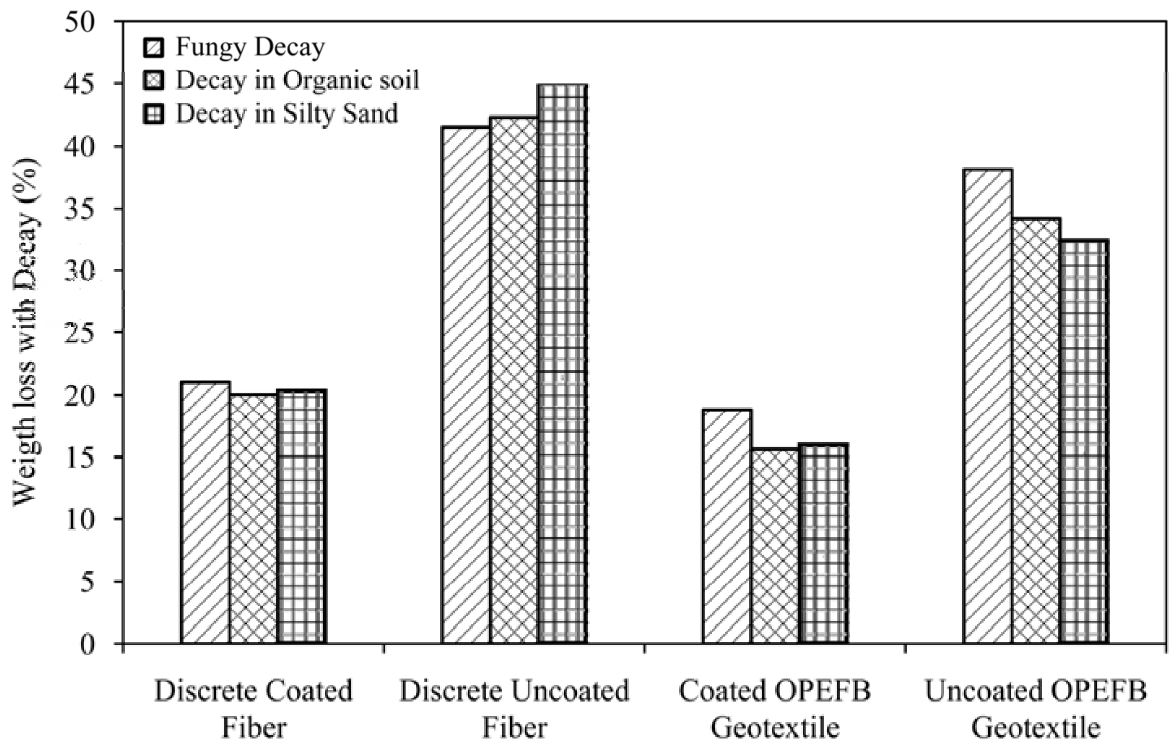


Fig. 18. Biodegradation of the fibres inside Silty sand, Organic soil and be in contact with fungus after 3 months

4. Conclusion

The thermoplastic was used as a treatment of the OPEFB fibres. The ABS coated fibres had an acceptable effect on the protection of fibre as the same as other treatment techniques. The water absorption of the coated fibre decreased due to protection capacity of the coated layer. The ABS coated fibre was found to be more durable compared to uncoated due to the condition of fibre. Morphological studies revealed that the coating modifies and protects the fibre surface entirely and the covered structure of the ABS over fibres can be seen from the respective scanning electron micrographs, also FTIR studies shown the chemical modifications within the ABS thermoplastic and fibres. From the tensile test it was found the Young's modulus of the coated fibre shown improvement due to ABS coating. However, the tensile strength of the fibre indicated less increase in comparison to untreated fibre.

The previous studies describe that inclusion of OPEFB fibres can significantly increase the peak shear strength of silty sand soil (Ahmad et al., 2010). The fibre content increment leads to increasing the shear strength and consequently stabilized the reinforced soil. Coated OPEFB fibres increased the shear strength of silty sand compared to uncoated fibres. Coated fibres shown higher interface friction between fibre and soil particles by increasing the surface area.

5. Acknowledgment

Also to all the collaborative partners and the working group committee especially to all the academicians, technical officers from other organization and technicians who have work closely in this project.

6. References

Ahmad, F.; Bateni, F. & Azmi, M. (2010). Performance evaluation of silty sand reinforced with fibres. *Geotextiles and Geomembranes*, Vol.28, No.1, pp. 93-99, ISSN: 0266-1144.

ASTM D4595-86 (2001) Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method. *ASTM International*, West Conshohocken, PA, www.astm.org.

Bateni, F.; Ahmad, F., Yahya, A. S. & Azmi, M. (2011). Performance of oil palm empty fruit bunch fibres coated with acrylonitrile butadiene styrene. *Construction and Building Materials*, Vol.25, No.4, pp. 1824-1829, ISSN: 0950-0618.

Huang, C.-Y. & Mo, W.-W. (2002). The effect of attached fragments on dense layer of electroless Ni/P deposition on the electromagnetic interference shielding effectiveness of carbon fibre/acrylonitrile-butadiene-styrene composites. *Surface and Coatings Technology*, Vol.154, No.1, pp. 55-62, ISSN: 0257-8972.

Jacob, M.; Thomas, S. & Varughese, K. T. (2004). Mechanical properties of sisal/oil palm hybrid fiber reinforced natural rubber composites. *Composites Science and Technology*, Vol.64, No.7-8, pp. 955-965, ISSN 0266-3538.

Maldas, D. & Kokta, B. V. (1990). Effect of Extreme Conditions on the Mechanical-Properties of Wood Fiber Polystyrene Composites .2. Sawdust as a Reinforcing Filler. *Polymer-Plastics Technology and Engineering*, Vol.29, No.1-2, pp. 119-165, ISSN 0360-2559.

MatWeb (Jun 2009). PTS Trilac® ABS-HS4000 General Purpose ABS Resin, In: *Matweb*, 8.6.2009, Available from: http://www.matweb.com/search/DataSheet.aspx?MatGUID=423e95f8367f42cbad42b991f6744516

Pavithran, C.; Mukherjee, P. S., Brahmakumar, M. & Damodaran, A. D. (1987). Impact Properties of Natural Fiber Composites. *Journal of Materials Science Letters*, Vol.6, No.8, pp. 882-884, ISSN 0261-8028.

Shah, A. N. & Lakkad, S. C. (1981). Mechanical-Properties of Jute-Reinforced Plastics. *Fibre Science & Technology*, Vol.15, No.1, pp. 41-46, ISSN 0015-0568.

Sreekala, M. S.; George, J., Kumaran, M. G. & Thomas, S. (2001). Water-sorption kinetics in oil palm fibers. *Journal of Polymer Science Part B-Polymer Physics,* Vol.39, No.11, pp. 1215-1223, ISSN 0887-6266.

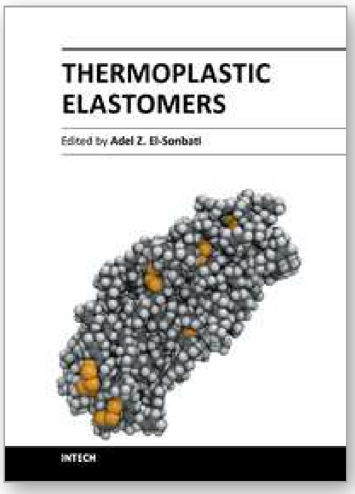
Sreekala, M. S.; Kumaran, M. G., Joseph, S., Jacob, M. & Thomas, S. (2000). Oil palm fibre reinforced phenol formaldehyde composites: Influence of fibre surface modifications on the mechanical performance. *Applied Composite Materials*, Vol.7, No.5-6, pp. 295-329, ISSN 0929-189X.

Sreekala, M. S.; Kumaran, M. G. & Thomas, S. (1997). Oil palm fibers: Morphology, chemical composition, surface modification, and mechanical properties. *Journal of Applied Polymer Science*, Vol.66, No.5, pp. 821-835, ISSN 0021-8995.

Sreekala, M. S. & Thomas, S. (2003). Effect of fibre surface modification on water-sorption characteristics of oil palm fibres. *Composites Science and Technology*, Vol.63, No.6, pp. 861-869, ISSN 0266-3538

Subaida, E. A.; Chandrakaran, S. & Sankar, N. (2008). Experimental investigations on tensile and pullout behaviour of woven coir geotextiles. *Geotextiles and Geomembranes*, Vol.26, No.5, pp. 384-392, ISSN: 0266-1144.

Yang, S.; Rafael Castilleja, J., Barrera, E. V. & Lozano, K. (2004). Thermal analysis of an acrylonitrile-butadiene-styrene/SWNT composite. *Polymer Degradation and Stability*, Vol.83, No.3, pp. 383-388, ISSN: 0141-3910.



Thermoplastic Elastomers

Edited by Prof. Adel El-Sonbati

ISBN 978-953-51-0346-2
Hard cover, 416 pages
Publisher InTech
Published online 28, March, 2012
Published in print edition March, 2012

Thermoplastics can be used for various applications, which range from household articles to the aeronautic sector. This book, "Thermoplastic Elastomers", is comprised of nineteen chapters, written by specialized scientists dealing with physical and/or chemical modifications of thermoplastics and thermoplastic starch. Such studies will provide a great benefit to specialists in food, electric, telecommunication devices, and plastic industries. Each chapter provides a comprehensive introduction to a specific topic, with a survey of developments to date.