

PROPERTIES OF MEDIUM-DENSITY FIBREBOARD (MDF) MADE FROM TREATED EMPTY FRUIT BUNCH OF OIL PALM

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NORUL IZANI MA, PARIDAH MT, MOHD NOR MY & ANWAR UMK. 2013. Properties of medium-density fibreboard (MDF) made from treated empty fruit bunch of oil palm. The objective of this study was to evaluate the physical and mechanical properties of experimental medium density fibreboard (MDF) panels manufactured from empty fruit bunch (EFB) of oil palm (*Elaeis guineensis*). Panels were made from EFB treated with boiling water, soaked in sodium hydroxide (NaOH) or their combination by using phenol formaldehyde at 8, 10 and 12% based on oven-dry weight of fibre. Mechanical and physical properties including modulus of elasticity (MOE), modulus of rupture (MOR), internal bond strength, thickness swelling and water absorption of the samples were determined according to the Malaysian Standards (MS 1787:2005). Based on results of this work, it seems that EFB can be used as raw material to manufacture value-added MDF with acceptable properties based on the standards. Panels made from fibres treated with NaOH in 12% resin produced the highest MOR (31.4 MPa). Fibres treated with the combination of NaOH and boiling water resulted in panels with reduced bending properties. All types of treatments enhanced dimensional stability of panels. All treated EFB fibres were less sensitive when exposed to alkaline condition compared with acidic condition.

Keywords: EFB, mechanical properties, dimensional stability, resin level

NORUL IZANI MA, PARIDAH MT, MOHD NOR MY & ANWAR UMK. 2013. Ciri-ciri papan gentian berketumpatan sederhana (MDF) daripada tandan kosong kelapa sawit yang dirawat. Objektif kajian ini adalah untuk menilai ciri-ciri fizikal dan mekanik papan gentian berketumpatan sederhana (MDF) yang diperbuat daripada tandan kosong kelapa sawit (EFB) (*Elaeis guineensis*). Panel ini diperbuat daripada bahan mentah yang dirawat dengan air yang dididih, rendaman dalam natrium hidroksida (NaOH) atau kombinasi kedua-dua rawatan dan direkat menggunakan fenol formaldehid (PF) pada tiga kepekatan iaitu 8%, 10% dan 12% berdasarkan berat kering gentian. Ciri-ciri mekanik dan fizikal termasuk modulus kekenyalan (MOE), modulus kepecahan (MOR), kekuatan ikatan dalaman, pembengkakan ketebalan dan serapan air sampel dinilai berdasarkan Piawaian Malaysia MS 1787:2005. Berdasarkan keputusan yang diperolehi daripada kajian ini didapati EFB dapat digunakan sebagai bahan mentah untuk membuat MDF dengan ciri yang mematuhi Piawaian Malaysia. Panel yang diperbuat daripada gentian yang dirawat dengan NaOH dan direkat menggunakan 12% fenol formaldehid menghasilkan nilai purata MOR yang tertinggi iaitu 31.4 MPa. Gentian yang dirawat dengan kombinasi rawatan menggunakan NaOH dan air yang dididih mengurangkan kekuatan lenturan panel. Semua jenis rawatan didapati meningkatkan kestabilan dimensi panel. Semua EFB yang dirawat kurang sensitif apabila didedahkan kepada keadaan beralkali berbanding dengan keadaan berasid.

INTRODUCTION

Accelerated deforestation and forest degradation, in addition to a growing demand for wood-based boards, have raised an important issue regarding the sustained supply of raw material to the wood-based product manufacturers. Therefore, to overcome this problem, researchers, both in industry and academia, are looking for new sources of lignocellulosic materials. Alternative

fibres such as agricultural residues and non-wood plant fibres could play a major role in providing the balance between supply and demand for the manufacturing of composite panels such as particleboard and fibreboard (Nemli & Aydin 2007).

Malaysia produces a large quantity of agricultural wastes such as oil palm (*Elaeis guineensis*) fibre. The area for oil palm plantation

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continues to increase, resulting in substantial residues within harvesting sites. It is estimated that overall, the oil palm industry generates at least 30 mil tonnes of lignocellulosic biomass per year in the form of trunks, fronds, empty fruit bunch (EFB) and leaves (Sumathi et al. 2008). EFB has an average cellulose content of 49–65% and offers the best prospect for commercial exploitation since it is readily available at the palm oil mill which minimises transportation and procurement costs.

There is currently considerable research concerning the use of oil palm biomass as structural component in various products, with results showing that this material has the potential to replace traditional wood and fibre derived from forests. Previous work using EFB in medium-density fibreboard (MDF) manufacturing has shown that such panels have inferior properties compared with panels made from rubberwood and other oil palm fibres (Paridah & Harmaen 2003). However, particleboard made from EFB has comparable properties with those manufactured from rubberwood, except for machining properties (Ratnasingam et al. 2007). Wood-based composite performance is mainly related to the properties of adhesive used, its compatibility with the fibre and properties of the fibre itself. Urea formaldehyde and phenol formaldehyde are the most commonly used adhesives to produce wood-based composites. In the case of EFB, the presence of residual oil in the fibres results in lower wettability of MDF which is more difficult to be glued or finished (Paridah et al. 2000). Removing residual oil from EFB fibres is necessary in order to improve bonding and overall properties of the final product (Ridzuan et al. 2002). Alkalinity and acidity of the raw material are also two important factors that need to be taken into account especially when wood-based composite production involves pH-sensitive binders such as acid-curing urea formaldehyde and alkali-curing phenol formaldehyde.

The alkalinity or acidity of the raw material influences the curing of binder (Paridah et al. 2001). Knowing the buffering capacity of a fibre helps determine the amount of buffering agent required in adhesive to prevent changes in pH at the glue line. The acidity or alkalinity can be measured by carrying out buffering

capacity test in which the alkalinity or acidity of a raw material is assessed by determining the volume of acid or alkali required to change the pH of the raw material to pH 3 or 11 respectively. Buffering capacity is the resistance of wood to change in its pH level. Wood that requires large amount of acid catalyst to decrease pH to the level required for optimum adhesive cure is considered as high buffering capacity species (Maloney 1993). The higher the volume of alkali needed to achieve pH 11, the higher the acidity of the raw material. Similarly, the higher the volume of acid required to achieve pH 3, the higher the alkalinity. Surface wettability and buffering capacity are two important characteristics of wood/fibre material that not only influence the rate of adhesive penetration and curing but also the extent of adhesion between wood and adhesive.

Recently, the treatment to remove residual oil in EFB fibre was done using sodium hydroxide (NaOH) and boiling the fibre in water. NaOH was reported to be more effective than water in removing residual oil (Ridzuan et al. 2002). Alkali treatment using limited concentrations of NaOH has also been reported to improve some of the mechanical properties of phenol formaldehyde-bonded composites (Ndazi et al. 2007).

Information on the use of oil palm biomass to manufacture exterior fibreboard is still very limited. The objective of this study, therefore, was to evaluate some mechanical and physical properties of exterior fibreboard panels made from treated oil palm EFB fibre bonded with phenol formaldehyde adhesive. The properties of experimental panels including modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength, thickness swelling and water absorption were evaluated to determine if EFB could be used as raw material to manufacture fibreboard panel product.

MATERIALS AND METHODS

Sample preparation

EFB fibre was obtained from Sri Langat Oil Palm Mill, Dengkil, Selangor, Malaysia. Treatment of EFB fibre to remove residual oil

was carried out by soaking in 2% NaOH for 30 min at room temperature, boiling in water at 100 °C for 30 min or a combination of the two (Ridzuan et al. 2002). Treated EFB samples were filtered out and washed several times with distilled water until free from NaOH, i.e. when the water no longer indicated any alkalinity reaction. For the NaOH-boiling treatment, EFB was soaked in NaOH for 30 min before being boiled in hot water for 30 min. Treated EFB specimens were sent to the Malaysian Palm Oil Board (MPOB), Bangi, Selangor where they were thermomechanically pulped to produce fibres.

pH and buffering capacity of EFB fibre

Aqueous fibre extract was prepared by refluxing 10 g of finely ground fibre in 100 mL distilled water for 1 hour. The mixture was then filtered using a filtering glass crucible number 2 attached to an aspirator vacuum to optimise extraction. The extract was diluted to 250 mL distilled water and stored at 20 °C for 24 hours before titration. NaOH (0.01 N) and hydrochloric acid (HCl, 0.01 N) were used to test acidity and alkalinity respectively. The extract mixture was titrated manually with HCl until it reached pH 3. These steps were repeated using NaOH until the pH value was 11. pH values were recorded for every 2 mL of titration. Three replicated measurements were made for each sample. The total volume of HCl or NaOH was calculated at the end of the test.

Preparation of medium-density fibreboard panels

MDF samples were manufactured at the MPOB. Both treated and untreated fibres were blended with phenol formaldehyde resin in a rotating drum-type mixer fitted with a pneumatic spray gun. Based on oven-dry particle weight, 8, 10 and 12% phenol formaldehyde resin was applied to the material. The blended fibres were then manually distributed into a wooden mould through a wire mesh. The hand-formed mats

were cold pressed before being hot pressed at temperature of 175 °C and at 160 kg cm⁻² for 5 min. Twelve boards (300 mm × 300 mm × 12 mm) and target density of 0.75 g cm⁻³ were manufactured. The samples were conditioned in a chamber at 20 °C and relative humidity of 65 ± 2% for 1 week.

Mechanical properties

After conditioning, test samples were cut and their mechanical properties (MOE, MOR and internal bond strength) determined according to MS 1787:2005 (Anonymous 2005). Static bending test was performed on 108 specimens (250 mm × 50 mm × 12 mm) using universal testing machine to obtain the MOR and MOE values. Internal bonding strength of the specimens was determined by tensile perpendicular to surface test.

Dimensional stability

Thickness swelling and water absorption were determined by measuring thickness and weight of the samples (50 mm × 50 mm × 12 mm) before and after immersing in distilled water at 25 °C for 24 hours. The percentage of water absorption and thickness swelling was calculated according to MS 1787:2005 (Anonymous 2005).

Statistical analysis

The effects of fibre treatments and resin content on the properties of panels were evaluated by analysis of variance (ANOVA) using a statistical analysis software (SAS). A least significance difference (LSD) method was used to identify the dominant factor and its interactions at $p \leq 0.05$.

RESULTS AND DISCUSSION

Buffering capacity

The buffering capacity values of the treated EFB fibres are presented in Table 1. When all

types of treated fibre were exposed to alkaline condition, NaOH treatment showed strongest resistance towards alkali as it required the largest volume of NaOH to reach pH 11. Extreme values of wood pH cause poor adhesive bonds (Paridah et al. 2001).

Each treated EFB fibre behaved differently towards acidic conditions (Figure 1). Conversely, these materials behaved quite similarly when exposed to alkaline condition (Figure 2). The rate of change in pH was greater in untreated fibre as shown by a steeper slope compared with treated fibres. Soaked fibre was more resistant to alkali, thus had greater buffering capacity towards alkali. The results of this study suggested that the NaOH-treated fibres developed more compatible bonding with alkali-curing resin such as phenol formaldehyde. However, the fibres were less resistant towards acid compared with fibres exposed to alkaline condition.

Mechanical and physical properties of the samples

There was significant interaction between types of treatment and resin levels for mechanical properties and internal bonding strength of the MDF made from EFB (Table 2). However, there were no interactions between types of treatment and resin levels for dimensional stability of panels produced (Table 3).

The mechanical, internal bonding and dimensional stability properties of MDF made from treated EFB bonded with phenol formaldehyde resin are presented in Table 4. All boards produced with phenol formaldehyde presented good mechanical properties. Generally, this resin produces stronger bond links than melamine and urea based resins (Iwakiri et al. 2005). Oil palm fibre and phenol formaldehyde resin are polar in nature due to the cellulosic hydroxyl groups in

Table 1 Buffering capacity of different EFB fibre treatments

Treatment	Initial pH	Volume of 0.01 N HCl (mL)	Volume of 0.01 N NaOH (mL)
Untreated	4.26	2.4	8.8
Boiling in water	4.53	1.6	12.4
Soaking in NaOH	7.80	13.2	18.4
Soaking in NaOH + boiling in water	7.07	6.6	13.2

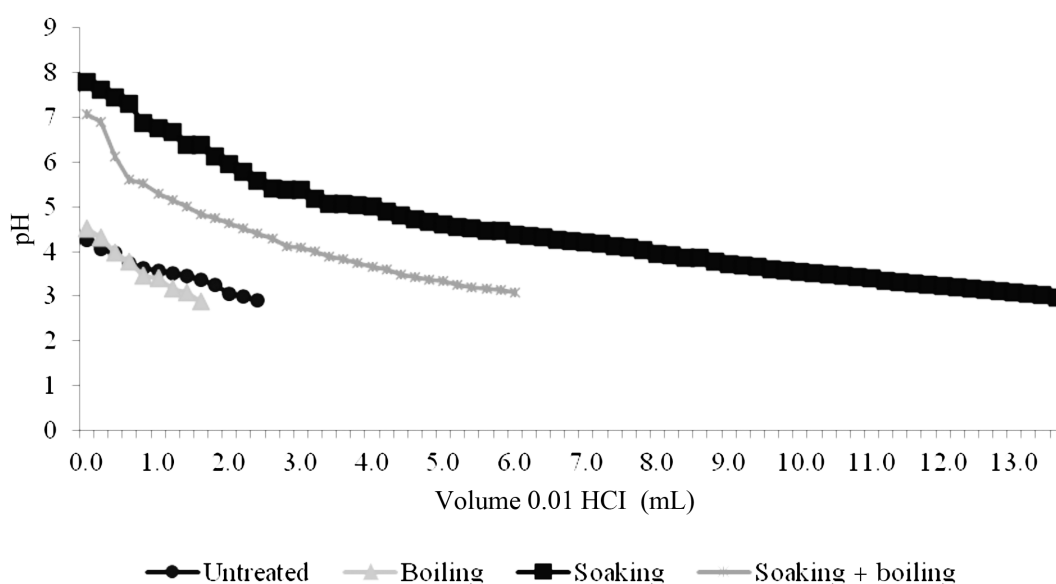


Figure 1 Comparative stability of different EFB fibre treatments towards acid

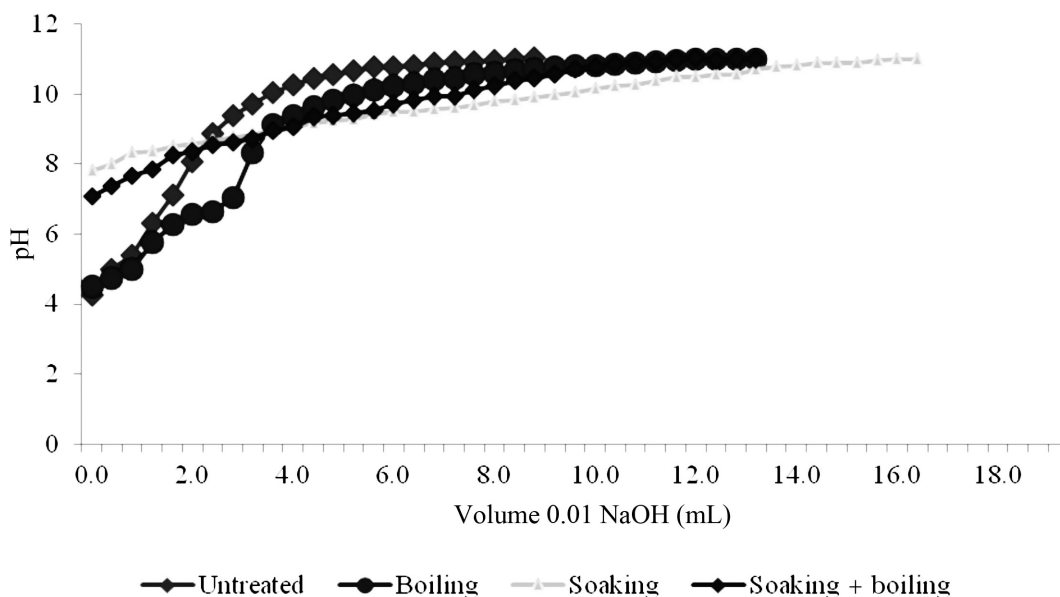


Figure 2 Comparative stability of different EFB fibre treatments towards alkali

Table 2 Analysis of variance for mechanical and bonding properties

Source of variation	Df	p value		
		MOR	MOE	IB
Treatment (T)	3	0.0001***	0.001***	0.0001***
Resin Level (R)	2	0.0001***	0.0001***	0.001***
T × R	6	0.017**	0.011**	0.0001***

** = significant at $p \leq 0.05$, *** = significant at $p \leq 0.01$; MOR = modulus of rupture, MOE = modulus of elasticity, IB = Internal bonding

the former and residual methylol groups in the latter. Hence higher compatibility is expected in oil palm fibre and phenol formaldehyde composites (Sreekala et al. 2000).

Samples made from untreated fibres had MOE values ranging from 2042 to 2255 MPa, while those using NaOH-treated fibres showed significant increase in MOE values up to 2437 MPa (Table 4). Elastic modulus of natural wood fibre is about 10,000 MPa, but elastic moduli of cellulose fibres obtained from wood fibre by chemical pulping processes can reach up to 40,000 MPa (Bledzki & Gassan 1999). NaOH treatment reduces lignin bonds between cellulosic fibres and partially hydrolysed hemicelluloses so that fibres are less damaged in subsequent refining processes. With lower percentage in hemicelluloses

content, the treated fibres produced fibreboards with higher MOE. Results of this study clearly showed that the mechanical and physical properties of fibreboards increased with increasing resin content.

Table 3 Analysis of variance for dimensional stability

Source of variation	Df	p value	
		WA	TS
Treatment (T)	3	0.0001***	0.0001***
Resin level (R)	2	ns	0.0001***
T × R	6	ns	ns

** = significant difference at $p \leq 0.05$, *** = significant difference at $p \leq 0.01$; WA = water absorption, TS = thickness swelling

Table 4 Test results of the samples

Treatment	Resin level (%)	MOR (MPa)	MOE (MPa)	IB (MPa)
Untreated	8	24.2 e	2042 c	0.21 g
	10	26.5 d	2132 c	0.24 g
	12	27.2 c	2255 b	0.34 e
Soaking in NaOH	8	28.2 c	2142 c	0.41 d
	10	29.6 b	2326 b	0.57 b
	12	31.4 a	2437 a	0.67 a
Boiling in water	8	17.6 g	1405 f	0.29 f
	10	19.1 f	1573 e	0.37 d
	12	19.4 f	1586 e	0.51 c
Soaking in NaOH + boiling in water	8	16.7 h	1308 f	0.31 e
	10	19.5 f	1626 e	0.39 d
	12	20.3 f	1751 d	0.47 c

Means with the same letters for each property are not significantly different at $p < 0.05$; MOR = modulus of rupture, MOE = modulus of elasticity, IB = internal bonding

In contrast, decrease in MOE in the boiling water-treated fibre can be attributed to poor adhesion and wettability of the fibre and heterogenous resin distribution in the composite. Exposure of fibres to high temperatures for extended periods lead to degradation. It is essential that process temperature should not exceed 100 °C because mechanical properties of fibres will be affected adversely (Pracella et al. 2006). Scanning electron microscope studies have shown that minor degradation of fibre occurs at process temperature of 100 °C (Hill et al. 1998). Boiling and the combination of NaOH soaking and boiling treatments did not show profound increase in MOR and MOE.

A significant improvement in bonding strength was achieved by the composite treated with NaOH. Alkali treatment leads to fibrillation which increases the effective surface area available for contact with the matrix, reduces fibre diameter and produces rougher surface compared with untreated fibre (Acharya et al. 2011). As a result of this, fibrillation may promote better mechanical interlocking (Li et al. 2005). In this case, better adhesion between fibres was found in NaOH-treated materials compared with those made from untreated fibres. However, no significant differences between the rest of the treatments

were observed. The findings in this work are in agreement with those of Weyenberg et al. (2006). Treatment of fibres by alkalisation helps in improving mechanical interlocking and chemical bonding between resin and fibre, thus, producing superior mechanical properties (Table 4). It has been reported that alkaline treatments on jute fibres (Ray & Sarkar 2001), bamboo (Das & Chakroborty 2006), coir (Prasad et al. 1983) and sisal (Chand & Hashmi 1993) have improved the fibre–matrix adhesion and hence enhances mechanical properties of these natural fibre composites.

The nature of adhesion between fibre and resin also had great influence on the final MOE as observed by the increase in the values with increase in resin level used. The fibre length of EFB is relatively much shorter compared with rubberwood which accounts for very low slenderness ratio or the length-to-thickness ratio. Since slenderness ratio influences the degree of interparticle bonding, a low slenderness ratio suggests that board made from EFB will have inferior internal bond strength compared with that of rubberwood, if the same resin formulation is used. In other words, higher resin content is required to have EFB final product with satisfactory properties.

Fibres produced from EFB are much finer compared with rubberwood. Thus, a good

resin distribution is needed to ensure sufficient resin–fibre contact. Smaller size fibre will also cause more resin absorption due to its larger surface area. Water absorption of EFB fibre in boiling treatment ranged from 43 to 68% (Figure 3). However, water absorption of the samples made using 8% resin content with different treatments did not show any significant difference.

Boards from NaOH-treated fibre had the lowest thickness swelling (Figure 4). These boards had higher internal bonding values compared with the rest of the treatments (Table 4). Lower thickness swelling values represent higher consistency between fibres which provides better dimensional stability and generally presenting higher internal bonding values. High water absorption and thickness swelling in products made from oil palm could be due to the inherent characteristic of oil palm being a hygroscopic material (Sulaiman et al. 2009). Overall, treated fibres resulted in better dimensional stability compared with those made from untreated fibres.

CONCLUSIONS

This study investigated the potential use of fibre resource from EFB of oil palm to manufacture value-added composite panel product. It appears that both physical and mechanical properties of experimental MDF samples made from EFB fibres produced satisfactory values based on Malaysian Standards. Treatment of raw material with combination of NaOH and boiling water had adverse influence on mechanical properties of samples. Increased amount of resin increased overall properties of panels. Further studies would be desirable to investigate additional properties such as overlaying and roughness characteristics as well as screw holding strength of panels to have a better understanding of their behaviour.

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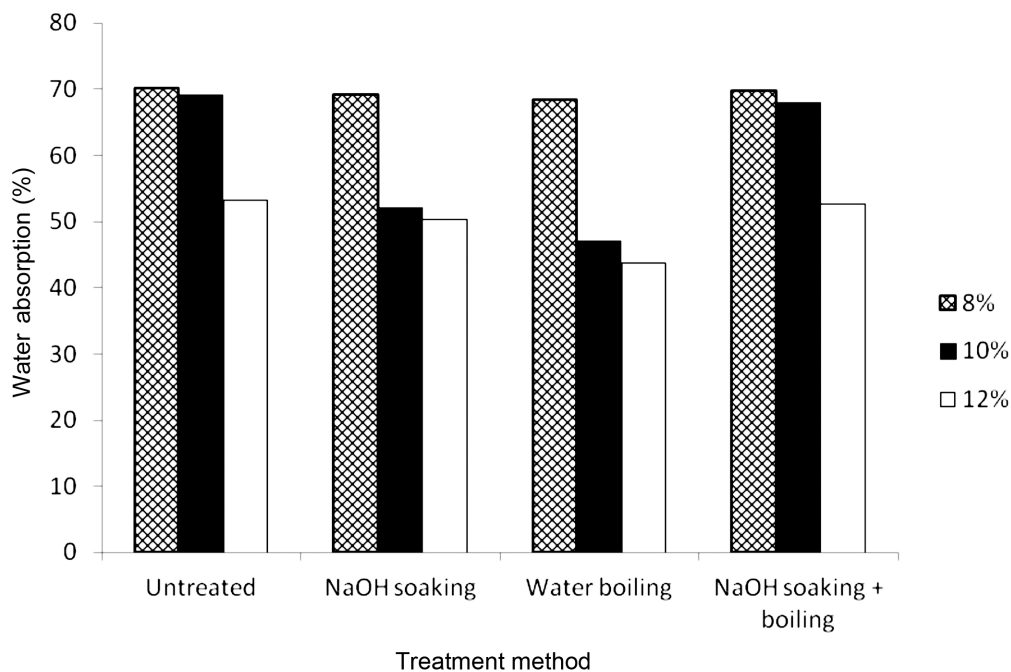


Figure 3 Water absorption of samples manufactured using treated EFB at different concentrations of resin

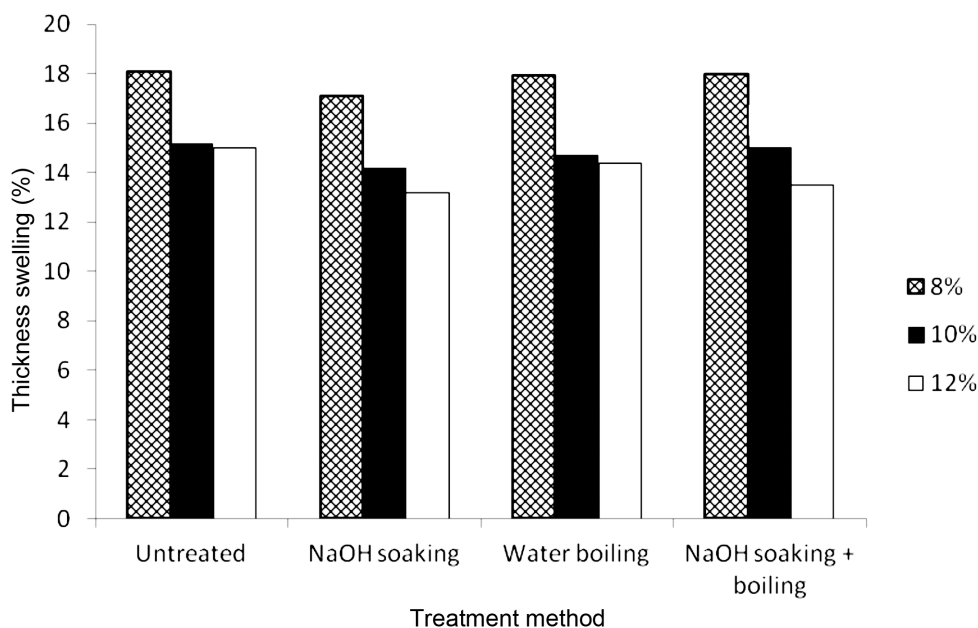


Figure 4 Thickness swelling of samples manufactured using treated EFB at different concentrations of resin

due to Sri Langat Oil Palm Mill for supplying oil palm EFB and the Malaysian Palm Oil Board for processing the fibress.

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