Materials and Design 52 (2013) 828–834

Contents lists available at SciVerse ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Development a new method for pilot scale production of high grade oil palm plywood: Effect of resin content on the mechanical properties, bonding quality and formaldehyde emission of palm plywood

Yeoh Beng Hoong [a,b,*], Yueh Feng Loh [a], Luqman Abd. Chuah [b,c], Idrus Juliwar [a], Antonio Pizzi [d], Md. Tahir Paridah [b], Harun Jalaluddin [a]

[a] Fibre and Biocomposite Centre, Malaysian Timber Industry Board (MTIB), Lot 152, Jalan 4, Kompleks Perabot Olak Lempit, 42700 Banting, Selangor, Malaysia
[b] Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[c] Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[d] ENSTIB-LERMAB, University of Lorraine, 27 rue Philippe Seguin, BP 1041 88051 Epinal, France

A R T I C L E I N F O

Article history:
Received 16 March 2013
Accepted 25 May 2013
Available online 6 June 2013

Keywords:
A. Natural materials
C. Surface treatments
E. Mechanical

A B S T R A C T

The main objectives of this research were to investigate the formaldehyde emission, some mechanical properties and bonding quality of oil palm trunk (OPT) plywood treated with low molecular weight phenol–formaldehyde (LmwPF), as affected by resin concentration. The mechanical properties are affected by different of amount resin solid contents used. The OPT veneer were treated at either 40%, 32%, 23% or 15% of resin concentration and 12 mm thickness of 3-ply plywood panel were manufactured for each group. In this study the formaldehyde emission, modulus of rupture (MOR), modulus of elasticity (MOE) and bonding quality (shear strength) of OPT plywood were determined. The results revealed that the resin-treatment method was tend to significantly improved the mechanical properties of the OPT plywood panel in which increased solid absorption gives better mechanical properties. Apparently, high mechanical properties were obtained for panel manufacturer from veneer treated with 32% and 40% resin content. The resin-treated OPT plywood provided superior mechanical strength with improvements at least 202% MOE and 159% MOR compared to commercial OPT plywood. Whereas, mechanical properties of the resin-treated OPT plywood were drastically decrease with increasing the water substitution. Formaldehyde emission content of OPT panels decreased upon reduction of resin content into treatment process and were significant at resin concentration. The resin-treated OPT panels at 32% solid content provided a reasonable amount of free formaldehyde (0.359 mg/L) which attained F^{****} according to Japanese Agriculture Standard (JAS). The shear strength of resin-treated OPT plywood panel with 32% and 40% resin content achieved minimum requirements according to the standard European Norms EN 314-1 and EN 314-2 for the interior and exterior application.

1. Introduction

The oil palm tree, belonging to the species namely, *Elaeis guineensis*, is one of the most abundant agriculture crops planted and can be obtained at any plantation around in Malaysia, Indonesia, Brazil and African countries. According to Malaysian Palm Oil Board, MPOB, statistic reported that the total area of oil palm plantation was 5.1 million ha in 2012 and it is expected increasing annually [1]. These trees were harvested and replanting for every 25 years rotation due to the reduction in production fruit and not economically for harvesting as the tree will reach more than 30-foot height.

During the harvesting, these agriculture residues were chopped into small disks and left in plantations for natural degradation which serves the purpose biomass as fertilizer, as fuels, burning, many are left unused and landfill. These lignocellulosic material from oil palm trunk materials it able to be value-added as source for composite, pulp and paper, particleboard, lumber, plywood and laminated veneer if under well management and implication. In fact, these agriculture biomass have been value-added and utilised by plywood manufacturer in Malaysia to produce oil palm plywood due to is sustainably, reasonably cheaper and abundant.

Oil palm trunk (OPT) has naturally highly variable physical properties which depend on factors such as planting location and the part of the trunk utilised (bottom to top and core to outer parts). This causes plywood made from oil palm veneers to have low mechanical strength, poor bonding properties and low dimensional stability which limits its applications compared to

* Corresponding author at: Fibre and Biocomposite Centre, Malaysian Timber Industry Board (MTIB), Lot 152, Jalan 4, Kompleks Perabot Olak Lempit, 42700 Banting, Selangor, Malaysia. Tel.: +60 12 4565631; fax: +60 3149 1607.
E-mail addresses: frence_yeoh@yahoo.com, yeoh@mtib.gov.my (Y.B. Hoong).

0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.05.082

conventional plywood made from tropical mix light hardwoods [2]. In order to increase its value in plywood application; several studies have been investigated and reported on the products to improve its poor nature properties. The effect of some processing variable on the physical, mechanical properties of the OPT plywood have been extensively studied by many researchers. The most of them started with density distribution [3], raw material preparation [4], type of veneer forming/lay-up [5], moisture content of veneer [6], different resin application [7], hot pressing pressure [8] and hot pressing time [9]. The resin treatment of wood by phenolic resin to enhance the mechanical properties, heat and flame resistance of final product has been studied since early half twentieth century. The low molecular weight resin has relatively, short chain, smaller molecules, and can easy penetrate onto wood cell, once its cured, thus improved the mechanical strength. The method of producing high mechanical strength plywood panels by treated with LmwPF resin has been reported by Loh et al. [10], Anwar et al. [11], Paridah and co-researcher [12]. Nonetheless, the effect of resin content on the mechanical properties, bonding quality as well as formaldehyde emission from the OPT plywood being reported by using these method. Formaldehyde gas is emitted from wide range of wood-based composite products. Formaldehyde is an organic compound and can be toxic, irritating, allergenic, and carcinogenic cause to human [13]. Formaldehyde has been significant effluent with human health problems either short or long term exposure to the gas. The American Cancer Society and International Agency of research on cancer (IARC) are classified formaldehyde as one of the 20 chemicals has potential cause of cancer that deserved more investigation [14]. Hence, several standards have been developed as the guidelines and regulation to facilitate the emission from wood-based such as perforator method (EN120) [15], large chamber method (ASTM: E-1333), desiccator method (JIS 1460) [16], chamber method (EN 717-1) [17], gas analysis method (EN 717-2) [18] and flask method (EN 717-3) [19].

Therefore, the objective of this study was to investigate the influent of the resin solid content of OPT veneer on the physical and mechanical properties and formaldehyde emission of OPT plywood panel. This work is the latter part of the previous two paper reported on a pilot scale study of high grade OPT plywood through resin treated method.

2. Experiments

2.1. Material preparation

The 25 years old OPT with 18 feet long (from the bottom part) and 30 cm in diameter were extracted from Sg. Lembu in North Malaysia. The OPT was then cut into 4 feet long (short core) and 8 feet (long core) sent to OPT plywood processing mill for veneers peeled at 4.5–5.5 mm thickness as raw material. Then, OPT veneers were cut into smaller size (3 × 4 feets), then dried using a conventional industrial dryer to a relatively MC of 5–10%. Only the veneers from the bottom (middle and outer) parts of the trunk were used as sample.

2.2. Preparation of LmwPF resin

Both type of commercial PF and LmwPF resin (Table 1), with solid content 40% that was prepared by reacting phenol and formaldehyde in an alkaline condition were used as the filling agent in the pre-treatment of OPT veneer [20,21]. Both resol type of PF were prepared with the resin cooking procedure were as the normal PF resin cooking for plywood with, minor modified where the methylolation period was maintained less than 4 h at a temperature below 80 °C for LmwPF resin and the final pH was adjusted to pH 10.

Table 1
Resin formulation at different types of LmwPF and commercial PF.

OPT plywood	Resin formulation resin:water	Solid content (%)
Panel A	100:0	40
Panel B	70:30	32
Panel C	50:50	23
Panel D	30:70	15
Commercial panel	Commercial PF	40

Note: Panels A–D were treated by LmwPF resin.

For commercial PF resin, the preparation was continued for at least another 4 h at 90 °C and final pH was set at pH 12. The molecular weight of both PF and LmwPF resin was carried out by using the water Gel Permeation Chromatography (GPC) Alliance E-2695 instrument separation module with a refractive index (RI) detector which is to detect the eluting peaks. Both resins were diluted to 2 mg/mL with dimethylformamide (DMF), which was also used as an eluent at a flow rate of 0.6 mL/min. The polystyrene was used as standard for calibration and the measurements were carried out at room temperature. The other physical testing and study of resin properties was carried out according to Nor Hafizah et al. [22]. The specifications of the resin used in this study were shown in Table 2.

2.3. Veneer enhancement

The details of treated method was carried out as described in published article of pilot scale production of high grade OPT plywood by Hoong et al. [8,9] Complied with the specials method of OPT plywood manufacture flows were reported by Loh and co-researcher [23]. The treatment process started with dried veneers immersed in different solid content (15%, 23%, 32% and 40%) of LmwPF and 40% for commercial PF resin, up to 10 s. After immersing, veneer samples were roller-pressed to ensure a dapper penetration of the resin into the veneer and to squeeze out any excessive resin. Immediately after pressing, the treated OPT veneers with penetrated resins were pre-cured through re-drying process at 70 °C with an industrial oven dried until below 20% moisture content.

2.4. Production of plywood panels treated with LmwPF resin

Three plies of OPT plywood with size of 4 × 8 feet were produced from total of 8 pieces (2 × 4 feet) short core (face and back) together with 1 long core (4 × 8 feet) of pre-treated with both phenolic resin. The veneers were lay-up in a cross laminated construction with and hot pressing time 20 min at 140 °C. The best practice pressing parameter to produce high strength OPT plywood would be determined based on the plywood mechanical properties (MOE and MOR). For the control, the process involved spreading the veneers with PF resin at spread rate 300 g/m^2 for each glueline.

Table 2
The specifications of the resin used in this study.

Specific of phenolic resin	LmwPF	Commercial PF
Basic solid content	40%	40%
Molecular weight		
– *Mw*	542	5132
– *Mn*	483	1030
– PDI (*Mw*/*Mn*)	1.12	4.98
Specific gravity	1.10	1.20
Viscosity	32 cP	105 cP
pH at 25 °C	10	12
Gel time at 100 °C	3719 s	1883 s

Note: *Mw* – weight average molecular weight, *Mn* – number average molecular weight, PDI – polydispersity index.