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Properties of particleboard made from rubberwood using modified starch as binder

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ABSTRACT

The objective of the study was to evaluate physical and mechanical properties of experimental particleboard panels made from rubberwood (*Hevea brasiliensis*) using modified starch as binder. Panels were manufactured using 15% corn starch modified with glutardialdehyde and tested for their properties based on Japanese Standard. The modulus of rupture and the internal bond strength of the panels met the requirement of the specified standard. Based on the findings in this work modified corn starch can have a potential to be used as binder to produce particleboard panels with acceptable properties.

1. Introduction

Rubberwood (*Hevea brasiliensis*) is one of the most commonly used raw materials to manufacture composite panels such as fibreboard and particleboard in Malaysia. Rubberwood originated as indigeneous species to the Amazon forest in Brazil was first introduced to South East Asia in mid 1800s [1]. In early 1990s Malaysia had a great success using rubberwood in manufacture of value-added products and became leader in South East Asia. The rubberwood sawn timber industry in Malaysia is well developed and used such resource as efficiently as possible. Currently waste materials from furniture and lumber manufacture and low quality small logs are the main raw material for composite panel producers in Malaysia.

Similar to wood composite industry in many other countries, formaldehyde based adhesives are also widely used in Malaysia. In the case of particleboard, urea formaldehyde is the most commonly used binder due to its fast curing time, clear color and low cost [2]. However one important disadvantage of such adhesive is its formaldehyde emission. The fundamental mechanism in formaldehyde emission from urea formaldehyde bonded particleboard is simply related to unreached free formaldehyde from the binder and hydrolysis of partially and completely cured adhesive. Several conditions of formaldehyde could be present such as monomeric formaldehyde entrapped between wood particles, as monomeric by hydrogen bonding of formaldehyde to the wood or as polymeric (solid) formaldehyde as well as loosely bound formaldehyde which could be easily released by hydrolytic reactions [3]. Formaldehyde emission from urea formaldehyde bonded panels gained attention as a public health concern last 30 years. It is well known fact that formaldehyde causes a significant health problems as well as environmental pollution. Of course very low concentration of formaldehyde in the atmosphere does not create any problems. For example, typical formaldehyde concentration in atmosphere is generally less than 0.1 ppm [4]. In one of the preview works, free formaldehyde percentage in urea formaldehyde bonded particleboard made from different European species were found less than 0.3 ppm. Also experimental particleboards panels manufactured from pine and spruce resulted in lower formaldehyde emission than those samples made from beech [5]. Wood composite industries in many countries try to control and reduce formaldehyde emission from the wood composite panels. There maybe two approaches to achieve that, namely to modify the chemical structure of the adhesive and reduce the amount of resin in board manufacture. However, even very little reduction of adhesive in the panels can significantly influence both physical and mechanical properties of the final product. Therefore some manufacturers are also interested in development and using non-formaldehyde base adhesive in their product line to eliminate such problem. Green and environmentally friendly materials including soybean and various types of starches would have potential to produce composite panels without having problems stated above.

Starch is carbohydrate materials that consist of amylase and amylopectin which could be differentiated by its chemical structure. The linear α-(1 → 4) linked glucan is called amylase while an α-(1 → 4) linked glucan with 4.2–5.9% α-(1 → 6) branch linkages is amylopectin [6]. It can be obtained from various plant

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materials such as corn, potato, rice, wheat, sago and many more and widely available throughout the world commonly used in food industries. Therefore, modification of starches were well documented by many researchers [7]. Various modifications of starch were evaluated, including through oxidation, esterification, etherification and crosslinking of starch. These processes yield, for example carboxymethyl starch, dialdehyde starch, hydroyethyl starch and starch xanthate [8]. Besides for food industries application, utilization of starch in non-food industries was also investigated by researchers, especially in the biodegradable thermoplastic field [9]. Although properties of rubberwood particleboard have been investigated in various works, currently there is no information on characteristics of composite panels made from rubberwood manufatured by modified starch as binder [1,10]. Therefore the objective of the work was to manufacture experimental panels from rubberwood and modified starch, and to evaluate both physical and mechanical properties of the samples to determine if they were similar to those of commercially manufactured particleboard panels.

2. Materials and methods

Commercially produced rubberwood (*H. brasiliensis*) particles supplied by a local particleboard company in Negeri Sembilan, Malaysia were used to make experimental panels. The particles were dried to 2% moisture content in a laboratory type oven. Corn starch in powder form modified with glutaraldehyde in liquid form in a ratio of 1:2 (w/w) was used as binder in a ratio of 15% based oven dry particle weight. Initially corn starch powder was dissolved in distilled water with a temperature of 30 °C before it was stirred and added 25% glutardialdehyde solution. Glutardialdehyde (GDA) is a colorless oily liquid organic compound with the formula of CH_2 $(CH_2CHO)_2$. It is widely used as disinfector agent for medical equipment. It has specific density ranging from 1.06 to 1.12 at 20 °C [11].

A total of 15 panels, five for each density level with dimension of 20.1 cm by 20. 1 cm by 0.5 cm was manufactured for the experiments, as shown in Table 1. Panels were made for target density levels of 0.60 g/cm^3, 0.70 g/cm^3 and 0.80 g/cm^3. Fifteen percent modified corn starch was manually mixed with rubberwood particles before they were processed in a computer control press using a pressure of 5 MPa at a temperature of 165 °C for 20 min. Panels were conditioned in a climate chamber with a temperature of 20 °C and a relative humidity of 65% for 2 weeks. After the samples were conditioned, their modulus of elasticity (MOE), modulus of rupture (MOR), internal bond strength (IB), thickness swelling, water absorption and surface roughness were evaluated based on Japanese Industrial Standard [12].

Both bending and internal bond strength test were carried out on using Tensile Strength Tester Machine Model 5582 (INSTRON) equipped with a load cell having 1000 kg each. Crosshead speeds of 10 mm/min and 2 mm/min were used for bending strength and internal bond strength, respectively. Thickness swelling and water absorption test were carried out by soaking 50 mm × 50 mm × 5 mm samples in water for 2 h and 24 h. Surface roughness profile were done on 15 samples with 3 readings taken for each samples using the Hommel Tester T500, which consists of the main unit and the pick up model TkE. The pick up has a skid type diamond stylus with 5 μm tip radius and a 90° tip angle. The stylus moves over the surface at constant speed of 1 mm/s over 15.2 mm tracing length. Vertical displacement of the stylus was converted into an electrical signal. Three roughness parameters, i.e., average roughness (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_{max}) were used for surface roughness evaluation of the samples. Specifications of these parameters were discussed in previous studies [5,13,14]. Determination of surface roughness is important as some coating materials really depend on the surface of the panels to work. Scanning electron microscopy (SEM) analysis was also carried out to see the interaction and distribution of the adhesive between the wood particles.

Characterizations of chemical and thermal properties of the manufactured particleboard were done. Infra-red spectra in the range of 4000–470 cm^{-1} of the particleboard were measured with FTIR spectrophotometer, (Nicolet, AVATAR FTIR-360), running Omnic software, to characterize the functional group inside the particleboard. To evaluate the crytallinity of the materials inside the particleboard, finely powdered samples were prepared from the IB test specimen, examined by XRD analysis using Diffraktometer D5000 Kristalloflex, Siemens. Step scan measurements were done using X-rays (Cu–Ka) at 40 kV and 40 mA. Scanning of 2θ was ranging from 10.0° to 40.0° corresponding to scanning speeds of 0.02°/min and 2°/min [15]. The crystallinity index (C Ir) was calculated using the formula:

$$\text{C Ir}(\%) = (I_{200} - I_{am})/I_{200} \times 100 \quad (1)$$

$$L = \frac{K \times \lambda}{\beta \times \cos\theta} \quad (2)$$

where I_{200} is the peak intensity corresponding to crystalline and I_{am} is the peak intensity of the amorphous fraction.

Thermal decomposition of the manufactured particleboards was done using a Metler Toledo TGA/SDTA 851 thermogravimetric analyzer, recorded from 30 °C to 800 °C for samples of 5–10 mg placed in an aluminum pan with a heating rate of 20 °C min^{-1} under a nitrogen atmosphere [16]. Differential scanning calorimetry, (DSC) Pyris 1, Perkin Elmer was used to evaluate the thermal behaviors of the manufactured particleboards, with heating rate of 10 °C/min. About 7 mg of powdered particleboard was added to an aluminum pan and sealed. An empty, sealed aluminum pan was used as reference. Then it was heated from −10 °C to 280 °C at the respective heating rate. Melting temperature of particleboard was determined from the obtained DSC curve.

3. Results and discussion

Table 2 displays test results of the samples. The highest average values of 3541 N/mm^2 and 20.38 N/mm^2 were found for MOE and MOR of the panels with density of 0.80 g/cm^3, respectively. These values were 59.41% and 58.35% higher than those of the specimens made with 0.70 g/cm^3 target density. The samples produced with 0.60 g/cm^3 density level resulted in the lowest bending properties

Table 1
Experimental design.

Particleboard density (g/cm^3)	Number of sample					
	Density	Thickness swelling	Water absorption	Surface roughness	Bending	Internal bond strength
0.60	30	15	15	15	15	15
0.70	30	15	15	15	15	15
0.80	30	15	15	15	15	15