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Measurement of some particleboard properties bonded with modified carboxymethyl starch of oil palm trunk

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ABSTRACT

The properties of an experimental particleboard made from rubberwood using carboxymethyl starch as a binder were evaluated for its mechanical and physical properties. Carboxymethyl starch was prepared by chemically modifying oil palm trunk starch with phosphoryl chloride. The panels produced were based on two target densities of 0.60 g/cm^3 and 0.80 g/cm^3 and four different types of binders, which were native starch, carboxymethyl starch, carboxymethyl starch mixed with 2% urea formaldehyde and urea formaldehyde as controlled samples. The starch was evaluated using X-ray diffractometry, fourier transform infrared spectroscopy, scanning electron microscopy, thermogravimetric analyzer, and differential scanning calorimetry. The specimens with a density of 0.80 g/cm^3 made using carboxymethyl starch showed an improvement in term of physical and mechanical strength compared to the panels bonded with native starch. The improvements in the properties of the panels were observed on the panels bonded using mixed binders which successfully achieved the minimum value specified by the standard.

1. Introduction

The wood-based panel industry is one of the major consumers of urea formaldehyde (UF), which is a petroleum-derived adhesive. Urea formaldehyde is widely used as a binding agent because of its ability to produce panels with acceptable strength and consistent quality at low cost [21]. Despite all of these positive attributes, the major drawback of UF is its formaldehyde emission, which has been proven to cause some serious health problems, including irritation to the eyes and respiratory tract, inability to concentrate, and fatigue [3]. To reduce the negative effects of UF reins via the formaldehyde emission, many wood based industries from all around the world are focusing on two different approaches which is either to reduce the percentage of formaldehyde based adhesive in board production or using the chemical modification technique to alter the chemical structure of the binders [25].

The reduction of formaldehyde based adhesives in board manufacturing significantly reduced the formaldehyde and carbon dioxide emission but it also slightly reduced the properties of the panels in term of physical and mechanical strength of the end products. To reduce the dependence on these petroleum-sourced adhesives as well as to eliminate the formaldehyde emitting problems, some board manufacturers decided on using non-formaldehyde based binders in their products [13]. Natural based adhesives were found to be one of the alternatives to reduce the rely on formaldehyde based adhesives. Since the last few decades, green products have become more popular due to the negative consequences related to the

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use of petroleum-derived products as well as due to the increase in petroleum prices [19]. Natural-based materials were known as environmental friendly and significantly not harmful to human health [10].

To address this problem, many researchers have focused on the development of new alternative raw materials from natural sources [19]. Starch from various sources is the example of natural-based material that would have a potential to be used as an adhesive in the board manufacturing [8,20]. It is a well-known natural resource, low cost, abundant, and suitable for chemical modifications that make it more stable and attractive as a substitute for synthetic polymers in various applications. For example, starch extracted from various sources also been used as an adhesive in applications such as sizing materials, glues, pastes, and binders [8].

In Malaysia, there are over 3 million hectares of oil palm cultivation, of which almost 80% is located within the Peninsular of Malaysia [14]. Usually, the oil palm tree is harvested after 25 years of planting due to decrease yield or increased height, which leads to difficult harvesting. Once a tree has been felled, burning or leaving the waste material on the ground to rot are common practices to dispose of oil palm trees. Both processes have disadvantages. Burning causes air pollution, while leaving the biomass to rot takes about more than 1 year for the tree to completely decompose, which hinders the process of planting a new crop [9]. To overcome this problem and at the same time applying the zero waste management solution which is very important in all wood based panel industry, starch extracted from oil palm trunk (OPT) that is considered as waste can be further processed as modified starch and have a great potential to be used as green adhesive [16]. Based on previous work by Hashim et al. [7], OPT contains the highest percentage of starch among all of the parts of the oil palm tree. The core part of OPT contains 17.17% starch, while 12.19% found in the middle part of the trunk. Normally, most of the starches extracted from the OPT are used in the food industry due to the high content of glucose [5].

Starch modification with phosphoryl chloride, $POCl_3$ based on the approach described by Kim and Lim [12], is one of the methods to produce carboxymethyl starch that further can be used to remove the presence of heavy metal ions in water. In this study, we would like to explore the potential of carboxymethyl starch to be used in the particleboards as a binder since the application of carboxymethyl starch based on OPT in particleboard manufacturing has not been investigated yet. Although $POCl_3$ was known as hazardous chemical according to Globally Harmonized System (GHS) [1], in this chemical modification, only a small percentage of $POCl_3$ is needed that is about 1% (w/w) to produce modified carboxymethyl starch to give high shear stress and highly stability [15]. For this application, the modified carboxymethyl starch is expected will reduce water absorption hence, producing panels with better dimensional stability in order to find the new alternative for reducing the usage of formaldehyde based adhesives [13]. This study was carried out to investigate the suitability of starch from OPT modified by a cross-linked reaction using $POCl_3$ as a cross-linking agent in experimental particleboard manufacture. Both physical and mechanical properties, along with a characterization of laboratory-made particleboard samples, were evaluated to determine the suitability and feasibility of manufacturing such panels at a commercial scale.

2. Experimental

2.1. Starch extraction and modification processes

The starch extraction process from the oil palm trunk was carried out based on previous work by Noor et al. [16]. Oil palm trunk samples were cut into smaller sizes (5 cm × 2 cm × 2 cm) and soaked in 1000 mL aliquots of a 0.5% (w/v) aqueous solution of sodium metabisulphite for 48 h. Following soaking, the oil palm particles were squeezed and filtered through a sieve with a mesh aperture of 75 μm. The collected filtered solution was centrifuged for 15 min at 4750 rpm using a Beckman Coulter Allegra X-15R centrifuge. The precipitated starch was carefully removed and dried in an oven at 50 ± 2 °C for 3 days. The dried extracted starch was weighed, ground, and stored in a dry bottle.

The oil palm starch was chemically modified using $POCl_3$ based on a method previously reported by Kim and Lim [11]. Following this method, 100 g of extracted oil palm starch was dispersed in 300 mL of distilled water, and the pH of the slurry was adjusted to pH 11.0 with 1 N sodium hydroxide (NaOH) solution. Next, 1 mL of $POCl_3$ was added dropwise to the slurry over 10 min while the pH of the slurry was maintained at 11.0 with NaOH solution. The slurry was stirred at room temperature for 1 h and then filtered with whatman No. 41 filter paper.

The filtered starch cake was dispersed in 300 mL of absolute ethanol, followed by the slow addition of a 50% NaOH solution (20 g). To the starch/ethanol dispersion was added 5% w/v of sodium chloroacetate ($C_2H_2ClNaO_2$), and the mixture was stirred at 45 °C for 2 h in a fully sealed container. After 2 h, the starch slurry was filtered and washed 3 times using distilled water (3 × 400 mL) and dried in the oven at 50 ± 2 °C for 3 days. The dried extracted carboxymethyl starch was ground by using a blender to obtain the powder form starch and stored in an empty and dried container for further use.

2.2. Particleboard manufacture

Rubberwood (*Hevea brasiliensis*) particles obtained from HeveaBoard Sdn Bhd, located in Seremban, Negeri Sembilan, Malaysia, were used as raw material in this work. Initially, the wood particles were dried in an oven at 50 °C for 7 min to ensure the moisture content of the particles between 4% and 5%. Using a grinder, the initial size of the particles was reduced to a mesh size of 1.5 mm in order to obtain two different sizes of particles.

A three-layer particleboard was produced based on two different target densities (0.60 g/cm^3 and 0.80 g/cm^3) with 3 replicates of panels for each set. About 15% of the carboxymethyl starch adhesive based on the oven dry (O.D) weight of the particles was used. Fine particles or