Properties of corrugated roofing sheet material from sugarcane bagasse fibers

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Abstract. This research was aimed to study the properties of corrugated roofing sheet material from sugarcane bagasse fibers by using 10% adhesive substances comprising Phenol formaldehyde (PF) and polymeric diphenylmethane diisocyanate (PMDI) resins. The corrugated roofing sheet had a density of 500, 700 and 900 kg m⁻³ and a thickness of 6 mm. Physical, mechanical and thermal properties tests were performed according to industry standards. The results revealed that sheets with high density had low moisture content, low water absorption and low thickness swelling. PMDI resin provided the best adhesive quality. As for the mechanical property investigation, modulus of rupture, modulus of elasticity, the impact strength. Regarding the thermal property investigation, were thermal conductivity and resistance covered. It was also found that the higher density they had, the better mechanical properties they owned. The PMDI-based corrugated roofing sheet with 900 kg m⁻³ density achieved the best mechanical properties. They can be highly possible to be used as a substitute material for asbestos roofing tiles.

1. Introduction

Thailand is predominantly an agricultural country. Apart from food crops, Thai farmers grow a great diversity of industrial crops such as sugar cane, corn, rice, nuts, and oil palm. The massive agricultural residues from these small and large-scale and mechanized farms traditionally considered as waste is increasingly viewed as potential raw materials for value-added products. The most agricultural wastes contain 3 main types of organic chemical components including cellulose, hemi-cellulose, and lignin in the ratio of 4: 3: 2 [1] approximately by gathering together in the plant cell wall. The idea of waste transformation is also applied to treat serious problem of disposal caused by invasive sugarcane bagasse fibers in natural fibers resources. Some of these biomass residues have been proved to be the great sources of high-quality natural fibers which can be used in many sustainable product lines. This research was attempted to develop the roofing sheets from sugarcane bagasse. Polymeric diphenylmethane diisocyanate (PMDI) and Phenol formaldehyde (PF) resin were used for roofing sheet forming process. They are the most used binders from high performing thermosetting adhesives utilized in fiber sheet industry. The studied investigation of the properties of roofing tiles manufactured from agricultural residues [2]. The stated that mechanical and physical properties of roof tile prepared from sugar cane
fiber[3]. The developed roofing sheets using groundnut shell particles as the main material and epoxy resin as the composite material [4]. The studied investigation of mechanical behavior of bagasse-aloevera as hybrid natural fiber composites[5]. The studied strength of corrugated roofing elements reinforced with coir [6]. The properties of roofing sheets depend largely on the adhesive systems, and also the adhesion between the fibers to adhesive bonding ability.

2. Material

2.1. Materials of preparing

In preparing the roofing sheet fibers, 2 types of thermosetting polymer were used; 10%wt diphenyl methane diisocyanate (PMDI) resin and 10%wt, Phenol formaldehyde (PF) resin were added to the first and second fiber mixtures, respectively. Regarding additives, 2% ammonium chloride as a hardener and 1% paraffin emulsion as a waterproof coating agent were incorporated. The required conditions for the entire process were as follows.

Sugarcane bagasse fibers received from sugarcane industry in Kanchanaburi Province. The sugarcane bagasse fibers were washed in water then treated by alkalization using sodium hydroxide (NaOH) for 24 hrs. The treated fibers were rinsed with water, dried, cut and ground to fine fibers. The ground fibers were sieved to an average particle size of 5 mm. as shown in Fig 1 and Fig 2.

![Figure 1. Cutting sizes of sugarcane bagasse fibers](image1)

![Figure 2. SEM images of sugarcane bagasse fiber](image2)

3. Methodology

The methodology conditions for the entire process were as follows

Both sugar cane bagasse were cut into small sizes not bigger than 5 mm. The sugar cane bagasse fibers had to be cleaned to remove the residual before fiber processing. They were then dried to obtain 3–5% moisture content before being mixed together at 100 %wt. ratio.

10% PF resin with 1% paraffin emulsion and 2% ammonium chloride were thoroughly combined and then sprayed onto the fiber mixture mentioned above. The PMDI-based batch was prepared in the same fashion as already described and density of 500 kg m⁻³, the sheet was molded from 700 g of each type of fibers. The fiber amount was increased to 900 g and 1,100 g to produce the roofing sheet with a density of 700 kg m⁻³ and 900 kg m⁻³, respectively.
In order to make a sheet, the mold with the dimensions of 400 mm in width, 400 mm in length and 6 mm in thickness was used. The adhesive-coated fibers was spread evenly in the mold. The obtained board was called a “preform board”. The hot press machine was used to manufacture the desired sheet by applying the force of 150 kg m\(^{-3}\) at 120 °C for 15 minutes.

The achieved roofing sheet had to be stored at ambient temperature for 24 hours to be ready for moisture content test. The achieved sugar cane bagasse fibers are shown in Fig 3.

![Figure 3. Corrugated roofing sheet made from sugar cane bagasse fiber](image)

3.1. Test specimens and test procedure
The physical, mechanical and thermal properties were tested as follows. In physical properties testing, water absorption test was performed according to JIS A 5908-2003 (8 type) [7], TSI 876-2547 [8], and TIS 535-2556 concrete roofing tiles [9]. The moisture content, thickness swelling, and water leakage were tested according to JIS A 5908-2003 (8 type). As for mechanical properties testing, modulus of rupture (MOR) and modulus of elasticity (MOE) were tested according to TIS Standard test procedure JIS A 5908-2003 (8 type). The impact strength test was done following ASTM D 256-2006a standard [10]. Thermal conductivity and thermal resistivity were tested according to ASTM C177-2010 [11]. All the tests were repeated on 5 specimens for average value finding.

4. Results

4.1. Densities
The densities of corrugated roofing sheet made from sugar cane bagasse fibers. The sheets were made with three different densities, 500, 700 and 900 kg m\(^{-3}\) using PF resin as the adhesive at 534.52, 732.26 and 919.45 kg m\(^{-3}\) for the roofing sheet with the density of 500, 700 and 900 kg m\(^{-3}\), respectively. Regarding the PMDI mixed group, the values were 560.15, 769.25 and 947.22 kg m\(^{-3}\), respectively are shown in Fig 4.

4.2. Moisture content
The average moisture contents of corrugated roofing sheet using PF resin as the adhesive accounted for 12.59, 9.93 and 7.68% of the sheet with the density of 500, 700 and 900 kg m\(^{-3}\), respectively. As for the PMDI mixed group, the values were 9.45, 7.13 and 4.25%, respectively are shown in Fig 5.

4.3. Water absorption at 2 and 24 hours soaking time
At 2 and 24 hours soaking time for the PF-mixed sheet, the three consecutive 500, 700 and 900 kg m\(^{-3}\) lots thus had the average water absorption of 25.15, 10.12 and 8.25% and 37.72, 12.19 and 10.82%, respectively. For the PMDI-mixed sheet at the two soaking time, the three batches with 500, 700 and 900 kg m\(^{-3}\) in density thus had the average water absorption of 12.21, 7.75 and 4.87% and 32.28, 7.24 and 6.56%, respectively. The results showed that higher density sheet yield lower water absorption value are shown in Fig 6.
4.4. Water leakage at 2 hours
At water leakage of corrugated roofing sheet using PF and PMDI resin as the adhesive accounted for 10% of the sheet with the density of 500, 700 and 900 kg m$^{-3}$, respectively. For the water leakage tested...
at 2 hours the results of leak proof test of roof sheet material from bagasse fibers did not appear to leak under the water the washed side of the sheet are shown in Fig 7.

Figure 7. Water leakage tested at 2 hours

4.5. Thickness swelling at 2 and 24 hours soaking time
For sheets with three different densities, 500, 700 and 900 kg m$^{-3}$, the PF-mixed lots thus had the thickness swelling of 8.92, 7.85 and 4.86% at 2 hour soaking time. The overall values went up to 9.45, 8.21 and 5.32%, respectively, at 24 hours soaking time. The PMDI-mixed sheet results with the same manner. After being soaked for 2 and 24 hours, the three batches gained 8.13, 6.72 and 3.94% and 8.92, 7.31 and 4.53% in thickness swelling, respectively are shown in Fig 8.

4.6. Modulus of rupture and modulus of elasticity
The average modulus of rupture (MOR) of corrugated roofing sheet using PF resin as the adhesive were 9.13, 18.22 and 20.42 MPa for the roofing sheet with the density of 500, 700 and 900 kg m$^{-3}$, respectively. For the PMDI-mixed group, they were 11.14, 23.46 and 25.97 MPa, respectively. For the average modulus of elasticity (MOE) of three mentioned densities, they were 1,609, 2,317 and 2,520 MPa for the PF-mixed roofing sheet while those using PMDI had 1605, 2,292 and 2,473 MPa respectively. It can be seen that the PMDI-utilized group possessed higher density and also MOR and MOE compared to the PF-mixed one are shown in Fig 9 and Fig 10.

Figure 8. Average thickness swelling at 2 and 24 hours of corrugated roofing sheet
4.7. **Impact strength**

For the three sets of PF-mixed roofing sheet according to their densities, 500, 700 and 900 kg m\(^{-3}\), the average impact strength were thus 0.85, 1.35 and 1.76 J. The PMDI system obtained 1.31, 1.87 and 2.95 J, respectively. As indicated by tensile strength measurement, the higher density roofing sheet provided the higher impact strength. The PMDI-based roofing sheet also presented the higher impact strength than the PF system. However the achieved impact strength was substandard due to typical particleboard specification standards are shown in Fig 11.

**Figure 9.** Average modulus of rupture (MOR) of corrugated roofing sheet

**Figure 10.** Average modulus of elasticity (MOE) of corrugated roofing sheet
Most of physical and mechanical properties of corrugated roofing sheet material produced from sugar cane bagasse fiber at 500 and 700 kg m\(^{-3}\) density can pass the specified standards the particleboard specification. For the 900 kg m\(^{-3}\) density group, all physical properties except the thickness swelling pass the standard. However, all mechanical properties of the 900 kg m\(^{-3}\) density corrugated roofing sheet material meet the requirements. Anyhow, the boards with increasing amount of fiber and adhesive have an issue of dissolving.

4.8. Thermal conductivity and Thermal resistance

Thermal properties of corrugated roofing sheet material produced from sugar cane bagasse fibers. For the three sets of PF-mixed roofing sheet according to their densities, 500, 700 and 900 kg m\(^{-3}\), the average thermal conductivity were thus 0.0125, 0.0132 and 0.0134 w/m.k and thermal resistance they were 0.3463, 0.3423 and 0.3393 m\(^2\).k/w. The PMDI system obtained 0.0129,0.0133 and 0.0135 w/m.k, respectively. Which were also and thermal resistance they were 0.3441, 0.3413 and 0.3388 m\(^2\).k/w. respectively. The experimental results showed that the thermal conductivity properties of sugar cane bagasse fiber has the best thermal conductivity followed, respectively. Since the amount of adhesive to be added to fibers the gaps or holes in the roofing sheet was getting smaller increasing the thermal conductivity are shown in Fig-12 and Fig 13.
5. Conclusion
In this study, the physical, mechanical and Thermal properties of corrugated roofing sheet material produced from sugarcane bagasse fibers were investigated. It showed that the sheet with 900 kg m$^{-3}$ in density the best performance. The moisture content, water leakage, water absorption, thickness swelling, modulus of rupture, modulus of elasticity and impact strength, can pass the standard specifications. Nevertheless, the mechanical properties of the 900 kg m$^{-3}$ density roofing sheet material were considered to be in the qualified range. The experimental results showed that the thermal properties of sugarcane bagasse fiber has the best thermal conductivity and thermal resistance. Since the amount of adhesive to be added to fibers the gaps or holes in the roofing sheet was getting smaller increasing the thermal conductivity are shown in Fig 2 and Fig 12 to Fig 13. The achieved roofing sheet material were suitable for material asbestos roofing tiles making.

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Figure 13. Average thermal resistance of corrugated roofing sheet
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