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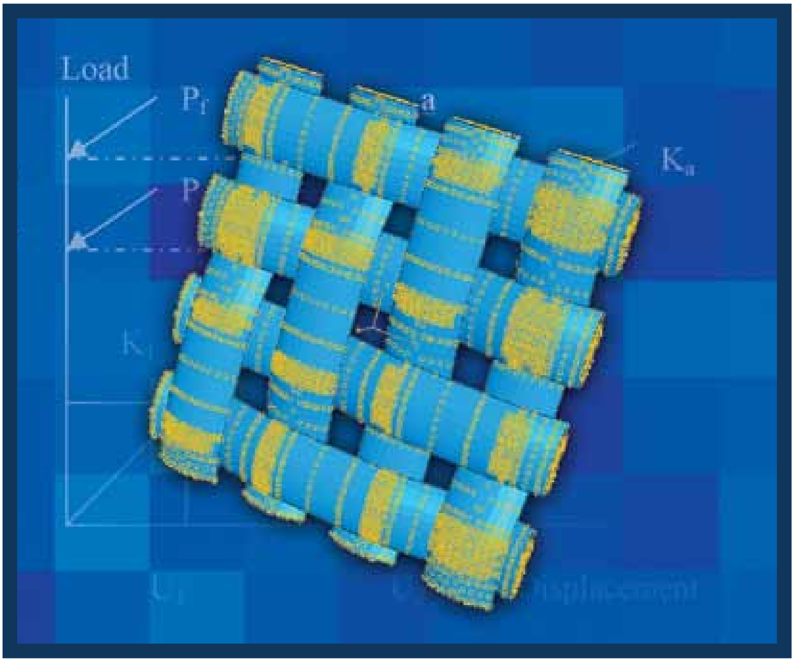

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The Properties of Agricultural Waste Particle Composite Reinforced with Woven Cotton Fabric

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ABSTRACT

The production of particle composites using agricultural waste materials is an area of significant research interest. In general the properties of agricultural waste particle composites are considered to be inferior to those of commercial particleboards. In this study, the inclusion of woven cotton fabric has been used to overcome this drawback. Particle composites were manufactures from coconut shell- and rubberwood-particles using urea formaldehyde as a binder and combined with woven cotton fabric to reinforce the material. The fabricated agricultural waste particle composites were then evaluated with respect to the effect of the number of fabric layers in the composite structure and the inherent effect on the mechanical (flexural and impact strength) and physical (water absorption and thickness swelling) properties. Agricultural waste particle composites without any reinforcement were used as control samples in this study. The test results indicate that the flexural and impact properties of particle composites reinforced with woven cotton fabric are better than those for the control samples. It was also determined that both the mechanical and physical properties improve with increasing fabric layers, except with respect to thickness swelling.

Keywords: *Particle Composite, Fabric Reinforcement, Flexural Strength, Impact Strength, Physical Test*

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Introduction

Particle composites were originally intended to replace modern plywood, because since the end of the 1940s there has been a significant reduction in the availability of lumber required for plywood manufacture [1,2]. Composites are heavily used in the construction of furniture and lightweight interior decorations, such as tables and chairs, kitchen cabinets, racks, cupboards, partitions, ceilings and wall components, as a consequence of its cheapness and density, but also because it tends to be more uniform than conventional wood and plywood [2]. Unfortunately the use of wood-based materials is increasing in-line with increasing living standards irrespective of the quantity of available wood resources.

In Malaysia, rubberwood is a prominent raw material used in the particle composite industry [2], however such high demand for this raw material has led to a rapid decrease in its former prevalence and a consequent supply shortage for manufacturers. In order to overcome this shortage, researchers are trying to develop alternative materials using agricultural waste, which is advantageous in that they are significantly cheaper than rubberwood [3-7].

Agricultural waste is a major contributor to environmental problems in that there are excessive quantities of agricultural waste, predominantly in the form of natural fibres, and the disposal of this waste is thus far inefficient. The transformation of bagasse, banana stem, paddy husk and coconut shell into particle composites is an effective solution by which to produce useful commodities whilst reducing agricultural waste. Unfortunately, an inherent property of particle composites is that they are weaker than rubberwood particleboard [4,5,7,8].

Combining rubberwood with agricultural waste is a means to can enhance the properties of agricultural waste particle composites thereby contributing to a reduction in the dependency on rubberwood and environmental problems caused by large volumes of agricultural waste. It is presumed that the addition of textile fabric to composites comprising of agricultural waste and rubberwood will exhibit better mechanical and physical properties than conventional composites.

This study has combined agricultural waste, specifically coconut shell, rubberwood and woven cotton fabrics into a composite particleboard. The resultant composite has been evaluated with respect to its flexural, impact, water absorption and thickness swelling properties, as well as the improved properties exhibited by the boards as a consequence of the inclusion of woven cotton fabrics, which reinforce the structure.

Experimental

Material

Rubberwood supplied by Nian Niaga Sdn. Bhd and coconut shell obtained from a coconut plantation in Sabak Bernam, Selangor, were bound together using a urea formaldehyde resin to construct the composite particleboards. Different layers of a medium weight woven cotton fabric supplied by Inovasi Uyon Enterprise were worked into the composite structure in order to investigate the effect of cotton fabric reinforcement, with respect to the number of layers, on the flexural, impact, water absorption and thickness swelling properties. The particle composites fabricated were; rubberwood and coconut shell, which constituted the control sample, rubberwood and coconut shell reinforced with 2 cotton fabric layers (2 LCR), rubberwood and coconut shell reinforced with 3 cotton fabric layers (3 LCR) and rubberwood and coconut shell reinforced with 4 cotton fabric layers (4 LCR).

Method

Rubberwood and coconut shell were manually crushed into small pieces using a hammer before being milled to produce particles. The particles produced were approximately 0.1 mm thick and were dried to 5% moisture content in an oven dryer. The resultant dried particles for both rubberwood and coconut shell were then mixed in a 50:50 ratio.

Resin was prepared by adding and mixing 2% ammonium chloride (hardener) to a urea formaldehyde (UF) solution; the consequent final binder mixture comprised of hardener and resin. The resin mixture was applied using spray nozzles mounted on the blender's rotating centrifugal applicators thereby ensuring a very fine spray and maximising bonding between the particles.

The particle/binder mixture was manually placed on a wooden mould (325 × 325 mm) alternately with layers of cotton fabric yielding a sandwich-like board. The fabrics were coated with UF before being placed upon the particle/binder mixture to ensure maximised adhesion between the surface of the mixture and the fabrics. Upon completing the layering process the resultant "sandwich" was cured using a hot press at 170°C for 6 minutes, Figure 1. The resultant 12mm thick cured boards were then left for one hour under normal conditions to attain room temperature.

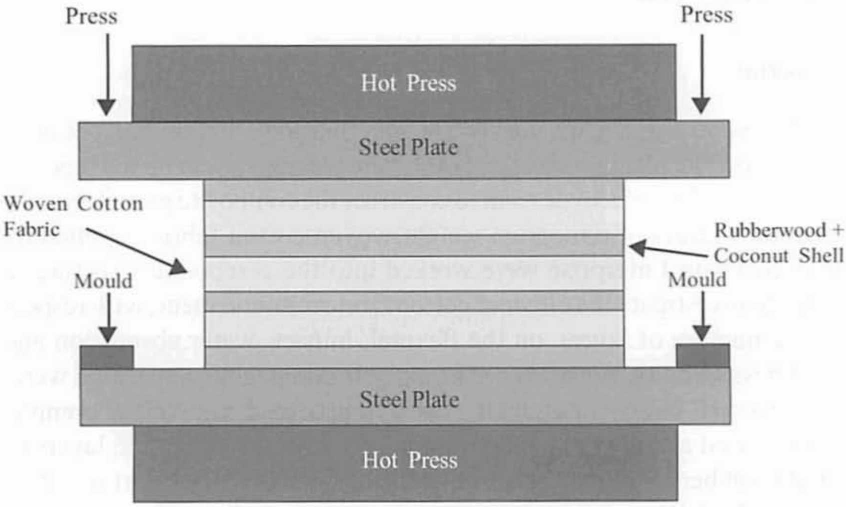


Figure 1: Schematic of the Hot Pressing of the Particle Composites Reinforced with Woven Cotton Fabric Layers

Flexural testing was performed on a Instron 3382 using the three point method in accordance with the British Standard, BS EN 310:1993 [9]. The length, width and thickness of the specimens were 290 × 50 × 12 mm, respectively, using a span length of 240 mm and a cross-head speed of 2.5 mm/min. Impact testing using a falling weight conducted on a Dynatup 8250, whereby samples were clamped horizontally and then struck by a vertically dropped weight. The line of initial contact, the distance from the centre line of the sample and the sample clamp, is maintained at a fixed distance for all samples.

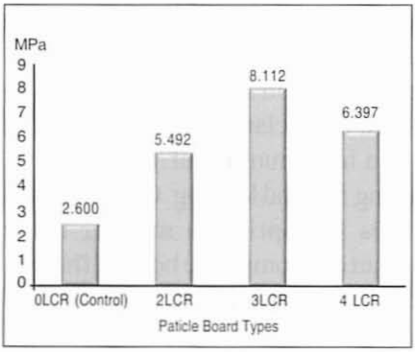
Water absorption and thickness swelling tests were performed in accordance with British Standard, BS EN 317:1993 [10]. Samples 50 × 50 × 12 mm with vertically clean faces were immersed in water of pH 7 ± 1 and 20°C ± 1. Sample weights pre- and post-immersion were recorded from which the quantity of water absorption was determined. Thickness swelling measurements, as a consequence of immersion in water, were preformed with respect to the average changes in sample thickness determined at four midway points.

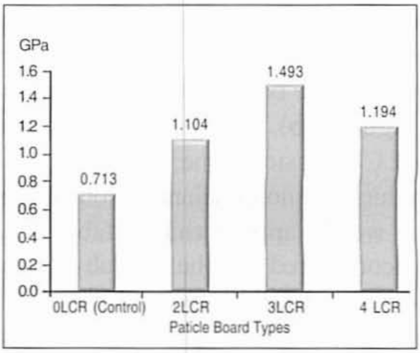
A Duncan Multiple Range Test (DMRT) and regression analysis were conducted in order to analyze the properties of agricultural waste composite samples with respect to the inclusion of woven cotton fabric layers and to determine a relationship between the board properties and the number of woven cotton fabric layers, respectively.

Results and Discussion

Figure 2 presents the results for the flexural testing of the agricultural waste particle composite boards reinforced with woven cotton fabric. It is evident that the presence of cotton fabric layers significantly influences the flexural properties (flexural strength and flexural modulus) of the boards. Figures 2(a) and 2(b) indicate that the agricultural waste particle composite boards which incorporated cotton fabric layers in their construction exhibit higher flexural strength and moduli than the control samples. The three cotton fabric layer samples (3LCR) exhibit the highest flexural strength and flexural moduli, which are approximately 212% and 109% higher than the values determined for the control samples, respectively. By comparison, composite samples with four layers (4LCR) exhibited lower flexural strength and flexural moduli than for 3LCR, which may indicate a limit on the number of cotton fabric layers that can be incorporated.

Table 1 presents the findings from the DMRT analysis of the composite boards flexural properties with respect to the number of woven





(a) Note: LCR = Cotton Fabric Layers (b)

Figure 2: Flexural Properties of Agricultural Waste Particle Composite Boards Reinforced with Woven Cotton Fabric: (a) Flexural Strength and (b) Flexural Modulus

cotton fabric layers. It is evident that there are significant differences in the flexural properties of the samples and that the flexural strength and moduli for 3LCR are significantly higher than those for the other samples. The DMRT analysis assigns the control samples to be in group 1, thus confirming that the presence of the woven cotton fabrics enhances composite flexural properties.

Table 1: DMRT Analysis of the Flexural Properties of Agricultural Waste Particle Composite Boards Reinforced with Woven Cotton Fabric: (a) flexural strength and (b) flexural modulus

(a)

Sample	Subset		
	1	2	3
Control	2.53381		
2LCR		5.24857	
4LCR		6.70847	
3LCR			9.15902
Sig.	1	0.195	1

(b)

Sample	Subset		
	1	2	3
Control	2.53381		
2LCR		1.14656	
4LCR		1.19441	
3LCR			1.71605
Sig.	1	0.819	1

Figure 3 presents flexure load-extension plots for 3LCR and 4LCR composite boards. The 4LCR composite boards exhibit little flexural loading thereby inferring that the inclusion of too many fabric layers reduces the flexural properties (flexural strength and flexural modulus) of the composite boards, unlike the 3LCR boards. This finding is further exemplified in Figure 4, which presents the typical flexure failure characteristics of the woven fabric reinforced agricultural waste particle composite boards at the edge surface of a tension zone. With respect to Figure 4 (b), it is evident that brittle shear and delamination occur at the 4LCR tension zone; a consequence of a high number of fabric layers, which promotes delamination thus reducing flexural loading. Consequently it would appear that 3 fabric layers is the optimum number to be incorporated into the agricultural waste particle composite boards, thereby offering flexibility yet reinforcing the board structure, since the 3LCR is able to withstand higher flexure loading.

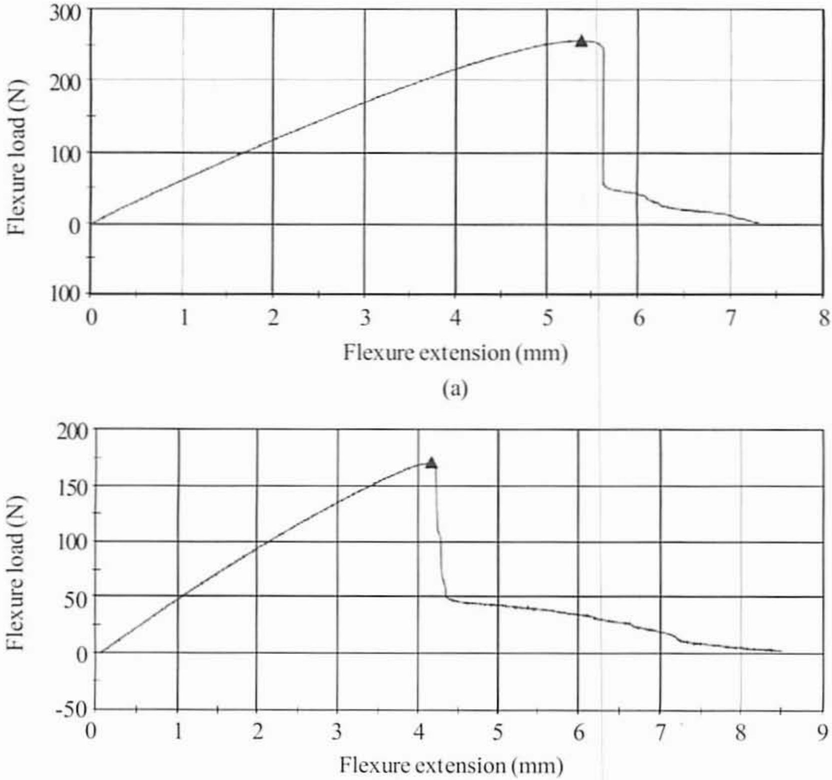
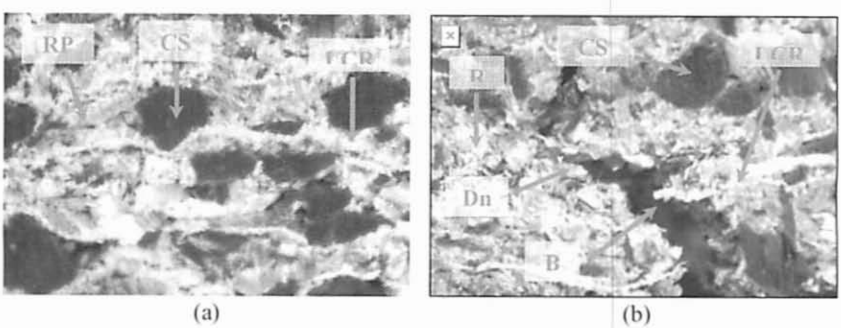


Figure 3: Typical Flexure Load-extension Plots for Agricultural Waste Particle Composite Boards Reinforced with Woven Cotton Fabric: (a) 3LCR and (b) 4LCR



Note: RP = Rubberwood Particle, CSP = Coconut Husk Particle, LCR = Cotton Fabric Layer, Dn = Delamination, BS = Brittle Shear

Figure 4: Typical Flexure Failure Characteristics of Agricultural Waste Particle Composite Boards Reinforced with Woven Cotton Fabrics at an Edge Surface Tension Zone: (a) 3LCR and (b) 4LCR

Figure 5 presents the results of the impact testing of agricultural waste particle composite boards. The increasing number of cotton fabric layers evidently significantly improves the impact strength of the boards; as expected a greater number of fabric layers results in a more impact resistant board. The impact strength of the composite boards is improved by between approximately 84-128% over the control sample results.

Table 2 presents the DMRT analysis of the impact properties of agricultural waste particle composite boards reinforced with woven cotton fabric from which it is evident that the impact strengths of the 4LCR composite boards are significantly higher than those of the other samples.

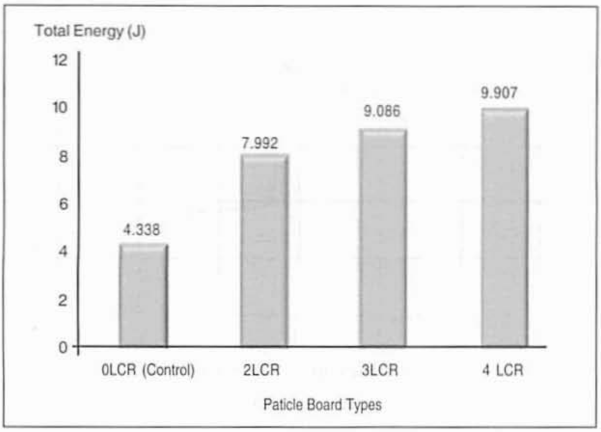


Figure 5: Impact Properties of Agricultural Waste Particle Composite Boards Reinforced with Woven Cotton Fabric

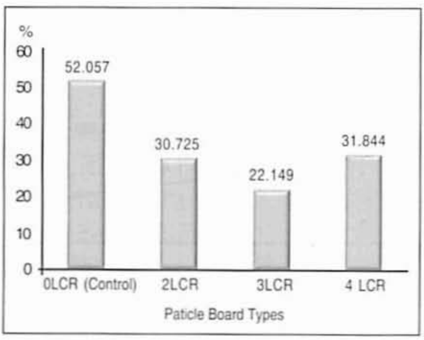
Table 2: DMRT Analysis of the Impact Properties of Agricultural Waste Particle Composite Boards Reinforced with Woven Cotton Fabric

Sample	Subset		
	1	2	3
Control	4.33816		
2LCR		7.99217	
3LCR		9.08563	9.08563
4LCR			9.90747
Sig.	1	0.189	0.315

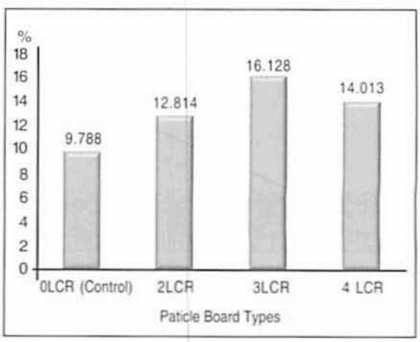
Figure 6 presents the results for the water absorption and thickness swelling tests performed on the agricultural waste particle composite boards reinforced with woven cotton fabric. The presence of cotton fabric layers significantly influences the water absorption and thickness swelling properties of the composite boards with respect to the control sample boards. Figure 6(a) presents the results of the water absorption analysis of the composite board samples whereby the 3LCR composite boards exhibit the least percentage absorption (22.149%), which is approximately 57% lower than that exhibited by the control samples. Interestingly the 4LCR samples have the second highest water absorption percentage, which may be attributed to improved accessibility to absorbent components in the composite structure and the consequent improved ability to trap water between the fabric and particle layers.

It is of significant interest that although the 3LCR composite board exhibits the most desirable properties, with respect to flexural strength and moduli, and water absorption, compared to the other composite boards considered in the presented work, it also exhibits the highest percentage thickness swelling (16.128%), Figure 6(b), which is less desirable. The increase in thickness swelling may be a consequence of the number of fabric layers, whereby the 2LCR, 3LCR and 4LCR composite boards all exhibit increased fabric layer-particle layer delamination.

Table 3 presents the DMRT analysis results of the water absorption and thickness swelling tests on the composite boards. The analysis indicates that the inclusion of woven cotton fabric in the construction of agricultural waste particle composite boards increases resistance to water absorption,



(a)



(b)

Figure 6: Water Absorption and Thickness Swelling Properties of Agricultural Waste Particle Composite Boards with Woven Cotton Fabric: (a) Water Absorption and (b) Thickness Swelling.

with respect to the control samples. However, analysis of the thickness swelling results indicates little or no significant improvement in performance as a consequence of fabric inclusion.

Table 3: DMRT Analysis of the Water Absorption and Thickness Swelling Properties of Agricultural Waste Particle Composite Boards Reinforced with Woven Cotton Fabric: (a) Water Absorption and (b) Thickness Swelling

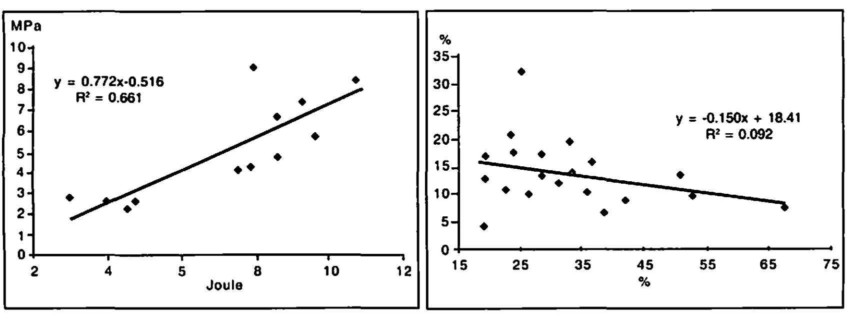
Sample	Subset		
	1	2	3
3LCR	22.14918		
2LCR	30.70533	30.70533	
4LCR		31.84446	
Control			52.05655
Sig.	0.055	0.787	1

(a)

Sample	Subset
	1
Control	9.78844
2LCR	12.81377
4LCR	14.01285
3LCR	16.128
Sig.	0.184

(b)

Figures 7(a) and (b) present the linear regression analysis of the flexural versus impact results and water absorption versus thickness swelling properties, respectively. In Figure 7(a) the flexural properties appear to have a linear relationship with respect to the impact properties since the coefficient of variation (R^2-value) is 0.661, which corresponds to a direct proportional association. It can therefore inferred that as flexural properties increase so does impact resistance. In contrast the results



(a) (b)

Figure 7: Linear Regression Analysis of Agricultural Waste Particle Composite Boards Reinforced with Woven Cotton Fabric: (a) Flexural Properties Versus Impact Properties, and (b) Water Absorption Properties Versus Thickness Swelling Properties.

presented in Figure 7(b) are far more scattered (R^2 = 0.092) thereby implying that there is little or no relationship between water absorption properties and thickness swelling.

Conclusion

Particle composite boards constructed from rubberwood and coconut shell particles bound together using a urea formaldehyde binder and reinforced with woven cotton fabric exhibit enhanced flexural, impact and water absorption properties. Unfortunately these boards are also swell to a greater degree than boards constructed with the absence of reinforcement. The flexural strengths, flexural moduli, impact strengths and water absorption resistance exhibited by the reinforced boards are better than those of the control sample boards by at least 111%, 55%, 39% and 31%, respectively. However, the presence of woven cotton fabric in the composite boards increases thickness swelling by at least 3% compared to the control samples. It can be concluded that the agricultural waste particle composites reinforced with 3 layers of cotton fabric exhibit the best flexural, impact and water absorption properties compared to the other samples considered and that the reinforcement of such composites using woven cotton fabric enhances the inherent flexural, impact and water absorption resistance properties.

Acknowledgements

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