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The Effect Of Weight Fraction And Size On The Properties Of Sago Particles Urea Formaldehyde Particleboard

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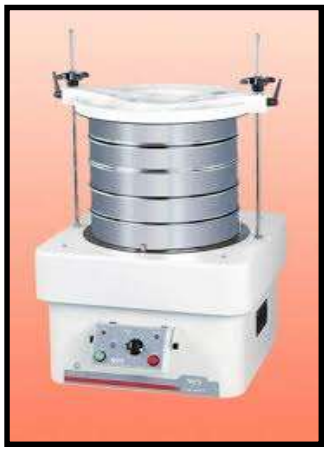
Graphical abstract



Abstract

We live in a world where wood products are hard to ignore. The sheer flexibility in the number of applications where the wood is used means that it is one of the most sought resources in the world. The wood products industry faces challenges in promoting sustainable management of forest resources. Composite materials have advantage of having an optimized performance, minimized weight and volume, cost effectiveness, chemical resistance and resistance to biodegradation. The research in this paper is focused on sago particles with adhesive of low emission urea formaldehyde (UF) resin 51.6% solid content. The fabrication and testing method are based on JIS A 5908 standard. A single-layer particleboard by using the sago particles has been established at targeted density level 600kg/m^3. Particles with weight fractions of 90%, 85%, 80%, 75% and 70% were used in the fabrication of sago composite boards. The results of the test demonstrated that the samples with different weight fraction and size have great influence on the mechanical properties like: MOR, screw test and internal bonding. The findings had demonstrated that the level of weight fraction and size had affects the performance of a board. At the next stage of the research the comparison between sago and wood particleboard will be carried out to identify the feasibility of these materials in the industrial application.

Keywords: Sago particles, urea formaldehyde resin, natural fiber composites, particleboard. mechanical properties

Abstak

Produk kayu pada masa kini sememangnya tidak dapat diketepikan. Kepelbagaian penggunaan berasaskan kayu menjadikan kayu sebagai salah satu sumber yang sering diterokai di dunia. Oleh yang demikian, industri produk kayu kini menghadapi cabaran untuk memperkenalkan pengurusan mampan sumber hutan. Komposit bahan mempunyai kelebihan dari segi prestasi yang optimum, jisim dan isipadu yang dapat dikurangkan, penjimatan kos, rintangan kimia dan rintangan untuk biogradasi. Kajian kertas kerja ini tertumpu kepada partikel sagu dengan pelekat urea formaldehyde (UF) resin dengan kandungan pepejal sebanyak 51.6%. Pembuatan dan kaedah ujikaji adalah berdasarkan standard JIS A 5908. Sagu papan telah direka secara selapis dengan sasar kepadatan pada aras 600kg/m^3. Penghasilan papan komposit sagu dibuat dengan berat pecahan yang berbeza iaitu 90%, 85%, 80%, 75%, dan 70%. Keputusan dari ujikaji menunjukkan sampel yang mempunyai berat pecahan dan saiz yang berbeza mempunyai pengaruh yang ketara dalam sifat mekanikal seperti: MOR, ujian skru dan ikatan dalaman. Hasil ujikaji telah menunjukkan bahawa aras berat pecahan dan saiz yang berlainan dapat mempengaruhi prestasi papan. Pada peringkat yang seterusnya , ujikaji perbandingan antara papan sagu dan papan kayu akan dijalankan bagi mengenalpasti kesesuaian bahan ini dalam kegunaan industri.

Kata kunci : Zarah sago, urea formaldehid resin, komposit serat semulajadi, papan sagu,sifat mekanik

1.0 INTRODUCTION

Mukah - Sarawak, East Malaysia is the biggest sago starch processing industries. Based on the research done by the scientist, it has been estimated approximately 7 tons of sago pith waste was produced daily from a single sago starch processing mill and these residues were washed off into nearby streams together with waste water and deposited in the factory's compound and which can lead to serious environmental problems.[1] Country like Indonesia was generated the sago waste among the year and they try to make use of the waste as useful material.[2] The main solution to overcome the depose problem was utilizing the agro-residues in order to achieve sustainable management of agricultural waste as composite material. As reported by the scientist large amounts of sago waste were decay naturally in the fields or burnt after the sago starch extraction process.[3] To assist the industry, extensive researches focusing on the use of biomaterials to produce environmentally friendly new materials have been carried out in recent years. Consequently, composite materials with qualities

such as, optimal performance with minimum weight and volume, cost effectiveness, and resistance to biodegradation have been created a for the market use. The interest in natural fibres reinforced polymer composites is growing rapidly due to the inherent qualities. Moreover, natural fibres provide good material performance at low cost and sustainable solutions for the green technology. The combination of natural fibres with polymers can be used as an engineering wood in sport equipment, automotive or aerospace industry. Due to the high physical and mechanical performance of the natural fibres in the composite industry, scientists have widely used their combinations for this purpose. To assist the wood industry, Sago will be the best raw material to replace wood, especially, in the furniture industry. The main reasons for selecting sago as a source of particle material in the future are their rapid growth, ecological adaptability and zero-waste. Scientist found out that not all lignocellulosic materials are suitable for making binderless board, however, they discovered that some natural fibres can be applied in binderless board due to its properties like, light weight and rich content of hemicelluloses.[4] Urea Formaldehyde (UF) resin is used as a major adhesive in the forest products industry due to its low cost, easy use under wide variety of curing conditions, low curing temperatures, water solubility, resistance to microorganisms and abrasion, good hardness, and excellent thermal properties. Many studies have been done on natural fibre UF based composites due to their acceptable physical and mechanical properties. The following research is an attempt to study the effect of sieving size and weight fraction on the mechanical properties of particleboard made from sago and UF resin.

2.0 MATERIAL AND METHODS

2.1 Sago Preparation

Sago particles were obtained from the Mukah region in Sarawak, Malaysia. The particles went through the sieving process for separation of particle size. <0.6mm, 1.18mm and 2mm sieving size of the particles were used in the experiment. After the sieving process, the particles were subjected to the drying process under the sun. The particles were dried in the oven with the temperature of 105^{0}C for 24 hours to achieve moisture content of less than 5% before the fabrication process. Figure 1 shows the sieving vibrator used in the sieving process. The output was cross checked by the HIROX KH-8700 microscope.

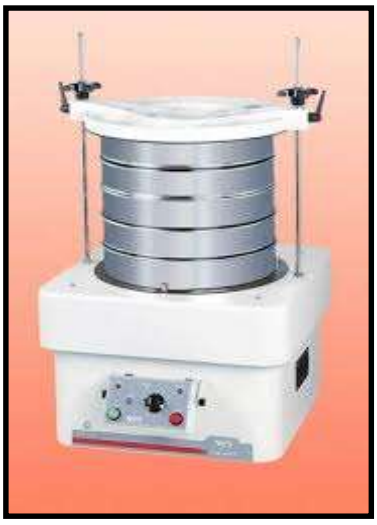


Figure 1 Sieving vibrator

2.2 Board Parameter

The target density was set at 600kg/m^3. The preparation of the board depended on the required sieving size and weight fraction. The parameters used in manufacturing the particleboards are shown in Table 1. Urea formaldehyde (UF) resin at 51.5% that serves as particle binder was obtained from Hexzachem Sarawak Sdn Bhd. The Urea-formaldehyde resin was used as a composite binder together with 1% of NH_4CI solution which acts as a hardener. The hardener was also obtained from Hexzachem Sarawak Sdn Bhd.

Table 1 Parameter for particleboard

Raw material	Sago particles o. <0.6mm, 1.18mm 2mm
Target board density	600 kg/m^3
UF resin	Solid content 51.5%
Hardener (NH_4CI)	1%
UF Appearance	White & opaque
Viscosity@30^{0}C	168CPS
Specific Gravity@ 30^{0}C	1.198
PH@ 25^{0}C	8.0
Solid Content hrs.@105^{0}C)	51.5%
Gel Time@100^{0}C	41sec
Free Formaldehyde	1.23%
Water Tolerance@30^{0}C	197%
Free Formaldehyde	1.23%
Board Size (cm)	30 x 30 x 1

2.3 Particleboard Fabrication

The sago particles were weighed based on the desired weight and were directly placed into the mixing drum that was equipped with an airless spray gun. The core particles were mixed by spraying them with urea-formaldehyde and hardener. After the blending process, the sago particles were spread evenly into the 30cm X 30cm wooden mould using stainless steel caul plate as the base. A thin layer of silicon glass mat was placed onto the caul plate to prevent the panel from sticking to the plate during the hot press process. The mat was pre-pressed manually to consolidate the thickness. During the hot press process, the distance bars were placed at both sides of the mat in order to get the targeted board thickness. The mat went through the hot press process under the temperature of 160^{0}C. The pressure of the hot press machine was set at 40 bar for 2 minutes and then gradually decreased to 20 bar and 10 bar for 2 minutes respectively. After the hot press process, the boards were kept in the chamber with humidity of 65±5^{0}C and 25±2^{0}C for two days curing process. The main purpose of curing is to stable the particleboards for the properties evaluation with the stable condition.

Figure 2 Mixing drum equipped with airless spray gun

2.4 Testing Method

The properties of the Sago particleboards were evaluated by using the Japanese Industrial Standard (JIS) for particleboards. [5] Three specimens with the measurement of 10mm X 50 mm X 150mm were prepared for three-point bending with 10mm/min loading speed. Three of 50mm X 50mm X 10mm size test specimens were prepared from each sample board for internal bonding and screw test. Specimens for internal bonding and screw test were tested by using the Instron machine with a loading speed of 2mm/min. Six specimens were tested for each case and the averages were reported as the obtained results. Mechanical tests on bending, internal bonding, and screw withdrawal were carried out by using the Instron Universal testing machine (model 5566).

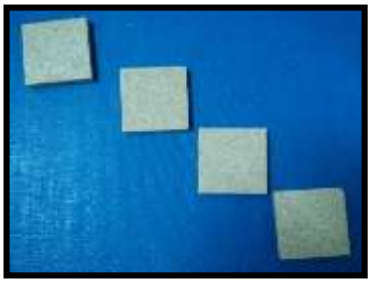


Figure 3 Screw and Internal Bonding Specimen

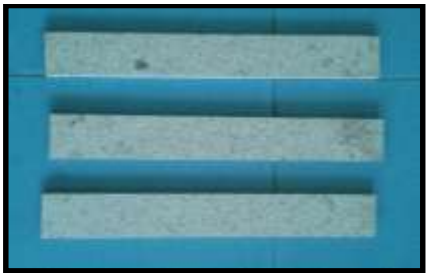


Figure 4 Bending Strength Specimen

Figure 5 Internal Bonding, Screw and Bending Test

■3.0 RESULTS AND DISCUSSION

3.1 Particle Sorting

The particles were sorted by the vibration sieve to the desired the particle size. There are less than 0.6mm, 1.18mm, 2mm and bigger than 2mm and was cross checked by the HIROX KN – 8700 (3D Digital Microscope). The dimension of the particles has a great influence on the final product. The sorting process will give particular effective when applied as raw material for the particleboard production. High performance of mechanical and physical properties on the particleboard can be achieved by an optimal size of the particles. The data were taken from a random selection with 200 units of particles for each size.

Table 2 Percentage of particles and the dimensions

PARTICLES SIZE	GROUP	RANGE	COUNT	PERCENTAGE %
0.6MM	G1	0.01mm – 0.1mm	56	28
	G2	0.11mm – 0.2mm	119	59.5
	G3	0.21mm – 0.3mm	19	9.5
	G4	0.31mm & above	6	3
1.18MM	G1	0.4mm - 0.5mm	65	32.5
	G2	0.51mm - 0.6mm	70	35.0
	G3	0.61mm - 0.7mm	52	26.0
	G4	0.71mm & above	13	6.5
2. 2.00MM	G1	0.2mm - 0.3mm	14	7
	G2	0.31mm - 0.4mm	119	59.5
	G3	0.41mm - 0.5mm	40	20.0
	G4	0.51mm & above	27	13.5

(a) 2mm particles

(b) 1.18mm particles

(c) 0.6mm particles

(d) dimension of the sago particles

Figure 6 The dimension of the sago particles under magnification 35 X

3.2 Moisture Content

Moisture content is a critical parameter for developing vertical density profile and a very significant parameter in particleboard production. High moisture content of natural particles will reduce the bonding of particles and matrix due to poor surface wetting. The moisture content should be maintained at the lowest during the fabrication process. Poor surface wetting for hydrophobic resin may cause interfacial shear bond and thus, lower the strength of a composite. When excessive moisture is migrated to the particleboard core, it requires additional pressing time to exit through the edges of the board to prevent de-lamination and spring-back condition when the press is opening. Excessive moisture may cause rapid densification of the surface and loosen the core, hence, resulting in poor mechanical test and may interfere with the polymerization of resin. The results a moisture content test in Table 3 show that the smallest size particle possesses higher moisture content than the biggest size. The size and shape of the individual particles in a furnace are significant factors that influence on the particles drying. The total drying time increases with the chip thickness because in the thinner particles, the maximum overpressure in the centre of material is higher because the distance for the transport of heat from the surface is halved and the main pressure release occurs in the longitudinal direction. When the longitudinal and latitudinal dimension is doubled, the maximum overpressure increases by a factor of more than two because of the larger length of longitudinal and latitudinal flow necessary for pressure equalization. The total drying time is longer in order to archive the equal volumes, a smaller particle is better for drying purpose than a bigger one, due to the highest resistance to flow in the thickness direction.

Table 3 Moisture content of the natural particles

Particles Size	Moisture Content (%)
Less than 0.6mm	9.486
1.18mm	8.248
2mm	7.595
>2mm	7.519

3.3 Mechanical Properties

Table 4 Mechanical Properties of Sago Particleboard Affected Size and Weight Fraction

Size	Weight Fraction	Bending Strength (N/mm²)	Internal Bonding (N/mm²)	Screw Test (N)
0.6mm	90%wt	4.75	0.60	63.33
	85%wt	8.86	0.56	135.47
	80%wt	7.35	0.45	166.45
	75%wt	5.57	0.45	95.23
	70%wt	3.67	0.33	69.69
1.18mm	90%wt	4.21	0.35	59.13
	85%wt	7.06	0.68	115.60
	80%wt	5.52	0.82	247.49
	75%wt	5.29	0.56	231.04
	70%wt	5.08	0.47	147.20
2.00mm	90%wt	3.93	0.72	78.16
	85%wt	6.25	0.62	167.27
	80%wt	8.06	0.38	224.86
	75%wt	4.64	0.34	106.59
	70%wt	4.63	0.28	105.06

3.3.1 Bending Strength Affected By Particles Size

The results in Table 4 show flexural properties gradually decreased with increasing particle size from 0.6mm to 2mm. The 0.6mm sieving size of sago particles had the highest bending strength compared to the other specimens. This could be due to the high compaction achieved by the 0.6mm particle size during the manufacturing process. There was sufficient matrix to bond the particles and this reduced the voids; resulting in better bending strength. Based on the statistics, it can be seen that about 60% of particles in the range of 0.11mm to 0.20mm shared geometrical similarity and this resulted in better bonding with each other and reduced voids. [3]

Coarse particles with 2mm sieving size had the lowest bending strength because the particles were too big and not able to transfer the stress during the test. Besides, poor adhesion between the UF matrix and the sago particle was conjectured, as there were voids around the sago particles where the particle can be pulled out easily. Failure occurred because the surface of the particles was not filled by the matrix. The large particles were de-bonded more easily from the matrix and led to void formation. The presence of voids that resulted from processing abnormalities and porosity of composites had reduced the flexure test. [6] Particle geometry is an important factor that affects their mechanical properties. Particles with a higher aspect ratio enhance stress transfer from the polymer matrix to the particles and finally improve the composite mechanical properties. [7]

3.3.2 Bending Strength Affected By Particles Size And Weight Fraction

Table 4 shows the relationship between bending strength and particle weight fractions with the size of 0.6mm, 1.18mm and 2 mm respectively. It is clear that the board containing 85wt% sago particles for both 0.6mm and 1.18mm sizes have the highest value of modulus of rupture (MOR). The MOR of 85% weight fraction of sago particles with the size of 0.6mm is 8.855 N/mm ^{2} while the MOR for the 1.18mm is 7.056 N/mm^2.

It can be seen that the particles with the size of 0.6 mm have better results compared to the particles with the 1.18 mm. This may be due to more exposure of the surface between the particle/matrix interaction in the particle reinforced composite. Basically, the larger surface area of reinforced material will provide better interaction between the polymer matrix and the particles. The chemical bonding accounts for adhesion between UF and the natural fibrous material. The higher bond strength obtained for UF matrix is due to the possible reaction between the methylol groups of resin with hydroxyl group of cellulose. [8]

The highest percentage of weight fraction did not show higher bending strength value because there was insufficient resin to wet all the fibers in the composite specimens. The MOR of samples with UF resins increased significantly from 90wt% to 85wt% for 0.6mm and 1.18mm sizes but particles with 2mm will be from 90wt% to 80wt%. This shows that the presence of resins resulted in improved bending strengths. With more resins available at higher resin content, more bonding sites are made available, thus, improving the strength properties and increasing the dimensional stability significantly; which can be attributed to the increase of the bond between the particles and hardening of the resin efficiency during hot pressing. [9]

At different weight fractions, the maximum MOR of the particleboard may be attributed to the different diameters of the particles and the compressive structure in the board cross section. MOR depends on the bonding strength between particles, individual particle strength and geometry of the particles. [4] The results in Table 4 show that by increasing the matrix from 90%wt to 85%wt, the stiffness of the composite material filled with 0.6mm particle size is greater than the stiffness of the ones filled with 1.18mm. However, the mechanical properties are reduced from 80% to 70%.

3.3.3 Internal Bonding (IB) By Particles Size

The internal bonding test results are displayed in Table 4. It can be seen that the particleboard with 1.18mm fiber size has the highest internal bonding strength compared with 0.6mm and 2mm fiber sizes. 1.18mm size of the particles has better bonding between the particles and matrix. As a result, the resin filled the gaps inside the core and increased the tension resistance.

0.6mm has the lowest internal bonding because the matrix did not flow smoothly between the particles and they were not fully penetrated by the matrix. The Internal bonding specimens will fail at the core of a particleboard because the core had the lowest density at the middle and tend to fail easily. The particle size and shape of fibres affect the internal bonding process. Fine and coarse particles will not contribute better strength to particleboards. The internal bonding strength can be improved by using the optimal particles size that is 1.18mm.

3.3.4 Internal Bonding (IB) By Particles Size And Weight Fraction

The internal bond test results are displayed in Table 4. In general, composite board with 1.18mm with 80wt% weight fraction had the highest internal bonding strength with the value of 0.816. The resin percentage increased when the IB strength was increased due to better adhesive binding between the binder and particles; resulting in a greater ability to withstand the perpendicular forces. The results of the test showed a trend that IB strength improved with higher resin loading. [10] The results also show that there was

an increase on internal bonding up to a certain limit as the fibre weight fraction decreased but then, these values decreased due to the evaporation of excessive matrix as steam.[10;11] The reductions of the IB values for particleboards may be attributed to insufficient or over sufficient curing of the resin.

It was found that different weight fractions of particles with resin affected the glue line which either slowed down or intensified the polymerization reaction rate. Thus, modification on the hot pressing time and temperature were required to fully cure the resin so that compact particleboards could be produced.[12] From the experiment, it was observed that some of the cured resins were retained on the particles surface; indicating insufficient penetration of resin. There were some areas on the particles surface without any trace of resin adhesive. The effects of interaction between the resin and particles were clearly seen in the experiment. The bonding strength between polymer matrix and lignocelluloses depends on the surface topology of the particles. [8]

3.3.5 Screw Test Affected By Particles Size

Table 4 shows 1.18mm sieving size of particles achieved the highest screw strength. This is because 1.18mm sieving size possessed good structure in the particleboard and the particles were sufficiently bonded by the matrix. The effective binding had increased the compatibility and enabled a screw to be fixed securely on the particleboard and resulted in better screw withdrawal reading.

Particles with 0.6mm sieving size had the lowest value in screw test because the small particles have week support structure and the matrix did not flow smoothly through the particles as the small particles were compacted together. Coarse particles were not bonded effectively during the fabrication and this created voids that caused failure in specimens during the test.

3.3.6 Screw Test Affected By Particles Size And Weight Fraction

As shown in the Table 4 , the optimal value of the highest withdrawal strength for all the sizes of the particles was 80%wt. From the observation, it was found that withdrawal strength improved at different levels as the resin content increased until certain limit of weigth fraction . The excessive matrix will cause the withdrawal strength to drop due to the matrix evaparation as steam during the hotpress process but not bonding the particles. The results show that 1.18mm sieving size with 80wt% weight fraction could withstand the highest load of 247.49N and had the highest face surface screw withdrawal strength.

The higher the resin content is, the higher the screw withdrawal load that it can endure. This is due to the ability of a board to bear the pulling force after being resinated with high resin dosage. The boards with high resin caused the screw to be embedded tightly and resulted in better screw withdrawal strength. The high compaction of a particleboard will increase the withdrawal strength because the particles were packed together with higher strength.

■4.0 CONCLUSIONS

From the obtained results, it is clear that sago particleboards with the size and weight fraction have an impact on the board performances. The boards' strength is enhanced when the resin loading is increased, but this is only applicable to certain percentage of resin loading and after that the strength will drop. Particleboards with 0.6mm with 80 wt% and 85wt%, 2mm with 80wt% met the M-0 specification of American National Standard A208.1-2009 for wood particleboards and fullfilled the industrial purpose.

Acknowledgement

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Appendix

Table 5 The IB, MOE and MOR values required to meet ANSI208.1 [13]

Class	Internal bond (N/mm^2)	Modulus of elasticity (N/mm^2)	Modulus of rupture (N/mm^2)
M-0	0.31	1380	7.6
M-1 Commercial	0.36	1550	10.0
M-S Commercial	0.36	1700	11.0
M-2 Industrial	0.40	2000	13.0
M-3 Industrial	0.50	2500	15.0