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# EFFECTS OF DENSITY OF SAGO/UREA FORMALDEHYDE PARTICLEBOARD TOWARDS ITS THERMAL STABILITY, MECHANICAL AND PHYSICAL PROPERTIES

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## Graphical abstract

## Abstract

This study examined the effect of density on the thermal stability, physical and mechanical properties of sago particleboard. Sago particles and Urea Formaldehyde (UF) were used as raw materials in the fabrication process. The fabrication and testing method were based on JIS A 5908 standard. The samples were prepared based on different desired density and went through a series of thermal stability, mechanical and physical tests. Mechanical properties of the composites were characterized by tensile, flexural, impact strength, screw test and internal bonding which had great influence on the particleboard performance. All the panels were tested for physical properties (water absorption and thickness swelling) to identify their use for indoor application. Thermal properties like thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) for the Sago/UF composites were analysed. The results showed particleboard with 800 kg/m$^3$ exhibited the optimum strength on Internal Bonding, Screw test, Bending and Flexure test. Particleboard with 700 kg/m$^3$ has better performance on Impact test. 500 kg/m$^3$ showed better curing properties with DSC. TGA showed that all the Sago/UF particleboard decompose with single-stage and were decomposed into three main steps like water absorption, volatile and char.

*Keywords*: Sago particleboard, Urea Formaldehyde, natural fibres, thermal stability, mechanical and physical test

## Abstrak

Kajian ini dijalankan bagi mengkaji kesan ketumpatan papan partikel sago terhadap kestabilan haba dan sifat-sifat fizikal serta mekanikal. Partikel sago dan Urea Formaldehyde (UF) digunakan sebagai bahan mentah dalam proses pembuatan papan tersebut. Kaedah pembuatan dan ujian yang digunakan adalah berdasarkan piawaian JIS A 5908. Beberapa sample telah dijalankan ujian kestabilan haba, ujian mekanikal and fizikal berdasarkan ketumpatan masing-masing. Sifat-sifat mekanikal komposit dikategorikan sebagai tegangan, lenturan, kekuata nimpak, ujian skru dan ikatan dalaman yang mempunyai pengaruh yang besar terhadap pretasi papan partikel. Di samping itu, bagi sifat fizikal (penyerapan air dan ketebalan kembangan), semua panel telah diujikaji untuk mengenalpasti kegunaan dalam ruang tertutup. Sifat haba seperti Analisis Thermogravimetrik (TGA) dan Differential Scanning Calorimetry (DSC) bagi komposit Sago/UF telah dianalisis. Papan partikel dengan ketumpatan 800 kg/m$^3$ menunjukkan kekuatan optimum dari segi ikatan dalaman, ujian skru dan ujian lenturan. Papan partikel berketumpatan 700 kg/m$^3$ mempunyai prestasi paling bagus dalam ujian impak. Papan partikel berketumpatan 500 kg/m$^3$ pula menunjukkan sifat kestabilan yang lebih baik pada DSC. TGA menunjukkan kesemua papan partikel Sago/UF mengalami

penguraian peringkat satu dan telah diurai dalam tiga cara utama iaitu penyerapan air, ketidakseimbangan partikel serta karbon.

*Kata kunci*: Sago partikel, Urea Formaldehyde (UF), gentian asli, kestabilan haba, ujian mekanikal dan ujian fizikal



## 1.0 INTRODUCTION

Nowadays, the wood industry is becoming an important part of our lives. Trees are widely used in the wood industry to produce furniture such as chairs, tables and cupboards. As we are living in an advanced and high technology environment, there is ongoing research on various composites to substitute the use of woods.

Researchers had come out with an idea using natural fibres mixed with thermoset or thermoplastic as composites to meet with the high demand furniture industries. Natural fibres like bamboo, coconut husk, cotton stalk, rice husk, pine needle, rice straw, non-edible grass are widely used in the composite industries [1]. Natural fibres have advantages such as low price, low density, high toughness, acceptable specific strength, recyclability and biodegradability. It can be used as raw material in the composite industries as the application of the following item such as floor boards, boards for acoustic damping, shipping crates, pallets and furniture [2, 3].

Until 2012, there are few types of particleboard had been created. However, the progress of those particleboard does not caught attention in the market and commercial industries due to the drawback provided. In India, CIROT Mumbai had produce the cotton stalk particleboard about 20 tons per day and the board were used as raw material for manufacturing particleboard [1]. IPI-RTI had use the rice husk to make the particleboard and the board has few constraints including the rough and porous surface on board, peel off at edges and process problem. Pine needle was used to manufacture the hard and pulp board but commercialize was not successful. IPIRTI has commercialized a type of hard board consist of rice and wheat straw. However, the rice and wheat straw have few constrains like high scattered distribution hence collect and storage problem, seasonal availability, high transport cost due to high volume with respect to weight, heterogeneity in quality and the technology. The properties of the raw materials, binders and additives have effect on the particleboard physical and mechanical properties [4]. Over the years many different lignocellulosic materials had been used in the particleboard production: coconut chips, paper sludge, waste tea leaves, castor stalks, wheat straw, flax shiv, kenaf stalks, needle litter, waste grass clippings, bagasse, saline creeping wild rye, peanut hull, cotton carpel, vine prunings, kiwi pruningds, waste tissue paper, corn peel and almond shell [5].

It is estimated that around 7 tons of sago pith waste was produced daily from a single sago starch processing mill [6]. The processing industries do not have a systematic disposal measures for this residues. Most of the times, they just wash off the residues into nearby streams together with waste water or the residues are deposited in the factory's compound [6]. Some of the processing industries leave the sago residues to decay naturally in the fields or burn them after the sago starch extraction process and this can lead to a serious environmental pollution [7]. Environmental pollution from sago residues can be reduced by combining the sago residues with the thermoset or thermoplastic to create a valuable product that benefits the environment [8]. This will provide an economic solution for the waste management system at sago mills and increase the awareness of public about the environmental friendly products [6].

Sago, also known as Metroxylon Sagu, is widely planted in Southeast Asia for example in Indonesia and Malaysia [9, 10]. The sago palm trees are grown commercially in Mukah, Sarawak and have long been proven to be advantageous. They are low cost, relatively sustainable, biodegradable waste, uniquely versatile, vigorous and promote socially stable agroforestry system [6].

Natural fibres are frequently used as reinforcement composite due to their good mechanical properties. However, the use of natural fibres has few drawbacks such as poor compatibility with thermoplastic matrix, high moisture absorption and low thermal stability. In order to use the sago residues in the furniture industries, the performance of thermal, mechanical and physical properties need to be evaluated to ensure they fulfill the standard requirement.

In order to achieve the best performance in the furniture industries, the dimension and stability of a particleboard need to be evaluated. The objective of this project is to investigate the thermal stability, mechanical and physical changes of a composite particleboard as an alternative to wood in the furniture industries.

## 2.0 METHODOLOGY

### 2.1 Materials

Sago residues, obtained from the local market in Mukah, were used as the raw materials in the sago/Urea Formaldehyde (UF) particleboards. Target

densities of the particleboard were set as 500 kg/m$^3$, 600 kg/m$^3$, 700 kg/m$^3$ and 800 kg/m$^3$. The UF with solid content of 51.5% was obtained from Hexzachem Sarawak Sendirian Berhad and was used as a binder. During the mixing process, 1% of $NH_4Cl$ was mixed with UF to act as hardener.

### 2.2 Particle Preparation

The sago residues were dried under the sun for two days and dried in the oven at 105°C for two hours before the fabrication start. In this experiment, particles with 0.6 mm size were selected and used in the fabrication. The sieving process was conducted using a sieving vibrator.

### 2.3 Calculation For Particleboard Set Up

Sago particleboards were fabricated based on the formula below:

Sample Calculation:

Target density: 600kg/m$^3$

Weight fraction of sago particles and UF matrix will be calculated based on the density setting.

Volume of the board, V=30 cm×30 cm×1 cm =900cm$^3$

Mass, m= density x volume= 900cm$^3$×0.6 g/cm$^3$ = 540g

Solid content of UF = 52.8% = 0.528

By setting 85wt% of sago particles and 15wt% of UF to be used

Amount of particles = 540g×0.85 = 459g

Amount of UF (including moisture)= 540g×0.15 = 81g

Amount of UF (without moisture)
= amount of UF (with moisture)/ UF solid content
= 81/0.528= 153.4g

Amount of $NH_4Cl$ to be used: 81g×0.01= 0.81g

Several trail of mixing process had been conducted. There were 90wt% particles + 10wt% matrix, 85wt% particles + 15wt% matrix and 80wt% particles + 20wt% matrix. The result showed 85wt% particles + 15wt% matrix has the highest mechanical properties and this had been chosen as the weight fraction of the raw material to be used in this experiment.

### 2.4 Fabrication of Sago/UF particleboard

Sago particles, UF and NH4Cl were weighed based on the desired weight and placed into the mixing drum before the mixing process. The sago particles were mixed by spraying them with UF that acted as a hardener to achieve a homogeneous distribution of adhesives on them. After the blending process, the sago particles were spread evenly onto wooden mould (with a dimension of 30×30cm$^2$) using a stainless steel 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 obtain the targeted board thickness. The mat went through the hot press process under the temperature of 160°C. The pressure of the hot press machine was set at 40bar 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% and 25±2°C to undergo a two day curing process. The main purpose of curing is to stabilize the particleboards before the properties evaluation process.

### 2.5 Verification Of Density Particleboard

6 pieces of Specimen with dimension 50mm X 50mm were cut from the sago particleboard and the board density were verification at Vertical density profile (VDP) and electronic densimeter MH-300S. This is to make sure the fabrication board achieved the desired density before the mechanical test, physical test and thermal analysis to be conducted.

### 2.6 Mechanical Test

The particleboards were evaluated according to Japanese Industrial Standard (JIS A 5908) [11]. Three point bending specimens were prepared with dimension 10×50×150mm$^3$ and the tensile specimens were prepared. Bending and tensile tests were conducted at 10mm/min loading speed. Specimens with a dimension of 50×50×10mm$^3$ were prepared from each sample board for internal bonding and screw withdrawal test. A screw with a diameter of 2.7mm was driven into the centre of each specimen until the head of the screw is parallel to the surface of the specimen. Specimens for internal bonding (IB) and screw withdrawal test were tested using the Instron machine (model 5566) with a loading speed of 2mm/min. For the Charpy Impact test, specimens were prepared based on the ASTM A370 standard with the width of 10mm, length of 55mm and thickness of 10mm [12]. The impact strength of the particleboards was measured by 50J Charpy Impact Tester LS-22 006. Six specimens were tested for each case and the averages were reported as the obtained results.

### 2.7 Physical Test

The water absorption and thickness swelling tests were carried out according to ASTM D 570 [13] standard at ambient temperature (25±2°C) and various time intervals up to 78 hours. The specimens were immersed

in a deionised water bath at 25°C for 2 hours, 24 hours and 72 hours respectively. After the immersion, the specimens were taken out and the surfaces were dried using a clean dry cloth. The specimens were reweighed to the nearest 0.1mg within 1 min for removing them from the water. The specimens were weighed regularly at 2 hours, 24 hours, 48 hours and up to 72 hours immersion. The water absorption and thickness swelling of each specimen were calculated by the weight and thickness differences.

The following equation is used for the calculation of the percentage of water absorption:

$$Water\ absorption(\%) = \frac{W_f - W_i}{W_i} \times 100\% \quad (1)$$

where $W_i$ and $W_f$ are initial and final weight of the specimen, respectively.

The following equation is used for the calculation of the percentage of thickness swelling:

$$Thickness\ swelling(\%) = \frac{T_f - T_i}{T_i} \times 100\% \quad (2)$$

where $T_i$ and $T_f$ are initial and final thickness of the specimen, respectively.

### 2.8 Thermal Properties

The thermal analysis (Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA)was carried out using TGA/DSCI STAR System, Mettler Toledo thermal analyser according to ASTM E1131.Small test pieces were cut from the sago particleboard and grounded in a wood pellet mill machine (YSKJ-120) as powder. Approximately 10 mg of the powder sample was placed in an aluminum pan and heated constantly at a rate of 10°C/min from 50°C to 800°C under 30 mL/min of nitrogen gas atmosphere. The weight loss and temperature were recorded and analyzed to determine the following TGA parameters: weight loss percentage, initial degradation temperature, volatiles in sample, and the residual weight percentage.

## 3.0 RESULTS AND DISCUSSION

### 3.1 Mechanical Properties

#### 3.1.1 Panel Density and Density Distribution

Figure 1 shows different density gradients observed for panels with different mean densities. It is understood that the density profile of a board strongly influenced the mechanical, physical and thermal properties. Based on the density profile, the density of a mat-formed particleboard is not uniform throughout the board itself. The skewed density profiles were due to uneven sanding of the board after manufacturing [14]. Density profile of a board was highly dependent on the particle configuration, moisture distribution, pressing time, temperature of the hot press, reactivity of the resin and the compressive strength of the component of the sago particles [15]. Most of the particleboards have higher density at the top and bottom regions compared to the core as these regions were exposed directly to the heat from hot-press plates [16]. When the rate of heat conduction from top and bottom plates is controlled, moisture dried up and hardens the sago particles especially on the surface of board. This produced layer with higher densities at the top and bottom of the board as there is less compression in the core layer. At the same time, the initial rapid press closing speed generated a higher pressure to the mat, which only allows a shorter time of heat and moisture to be transferred into the core layer resulting in a lower density of core.

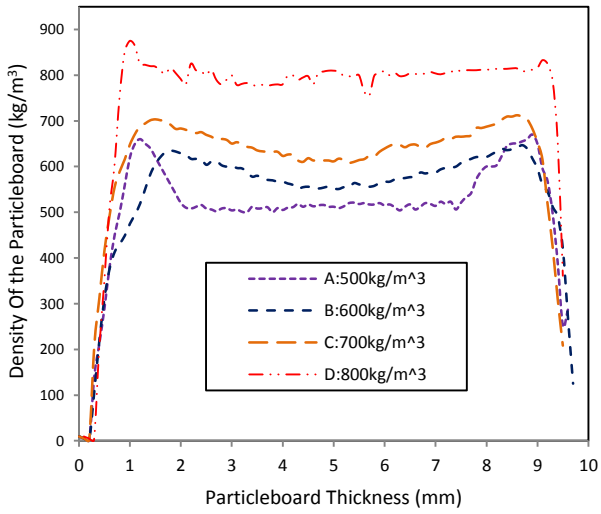


**Figure 1** Density profile of the particleboard

Sample D has a uniform density profile and was found to possess homo-profile properties. Wong *et al*. (1999) explained that homo-profile boards have a significant influence on the mechanical test and correlated with the board mean density [17]. This is due to a higher density closer to the surface that increases the flexural strength.

Sample A was found to have a U shape density profile [15]. This is due to higher moisture content within the fine particles on the panel surfaces. Moisture in the top and bottom of the board dried up completely by the hot-press heat. The higher initial pressure with short closing time during the hot pressing process resulted in higher face of density [18].

Sample B and C have M shape profile and categorised as a conventional particleboard [14]. M shaped density profile is produced when the closing speed decreased. A long press closing time helps to facilitate stress relaxation in a board before the final thickness is achieved. With a longer press closing time, the adhesive will polymerize on the surface before sufficient inter-particle contact occurs inside the board. Other factors such as heat, moisture transfer and resin cure are also affected by the change in press closing speed [19].

### 3.1.2 Bending Strength(MOR)

Figure 2 shows the effects of board density on the Modulus Of Rupture (MOR) of sago particleboards. Based on the experiments, the MOR shows a significant increase when the board density increased from 500 kg/m$^3$ to 800 kg/m$^3$. The results show sample D had the highest bending strength whereas sample A shows the lowest bending strength.

Sample D shows the highest MOR value because the particles and the matrix of the board have a better bonding. Therefore, the number of void spaces of sample D at 800 kg/m$^3$ are reduced and resistance to rupture is enhanced. This can be attributed to the greater compression ratio and better particles bonding within boards, leading to better contact area between the resin and sago particles which had resulted in high strength properties [20, 21, 22].

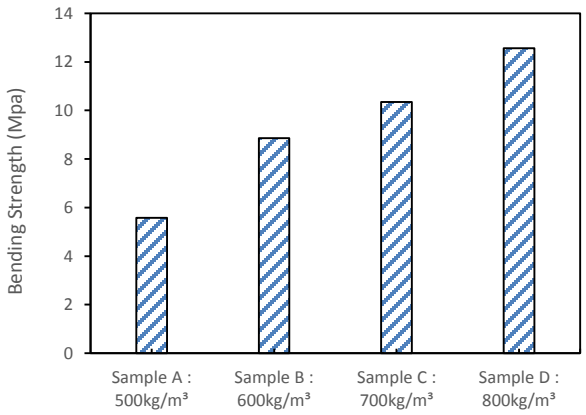


**Figure 2** Effect of density on bending strength

A has the lowest MOR value due to the porous structure applied on the specimen and reduction in inter particles contact area which had resulted in the formation of weaker bonds [20].

The MOR value increases when the density increased from 500 kg/m$^3$ to 800 kg/m$^3$. This is because the areas of stress concentration around the component particles are more diffused when the sago particles occupy more volume in the board which resulted in increased applied stress [23]. The molecules have less room to displace with the same force as the material becomes denser thus, leading to a higher stiffness [24]. An increase in the bending strength may be due to the higher density in the face layer compared to others [15].

### 3.1.3 Internal Bonding (IB)

Figure 3 shown that density has significant effects on the internal bonding strength. Sample D has the highest internal bonding strength while sample A has the least. The internal bonding of particleboard is directly influenced by board density.

By increasing the board density, the internal bonding strength also increases and this is similar to observations made by other researchers [25]. Higher compaction ratio at higher density had increased the strength and resulted in harder panels [25, 26].

According to Eslah (2012), board density is one of the important factors which will affect the properties of particleboards and other wood composites; denser panel results in higher mechanical properties [22, 26]. Furthermore, it provides better quality for inter-particle contacts under compression [27].

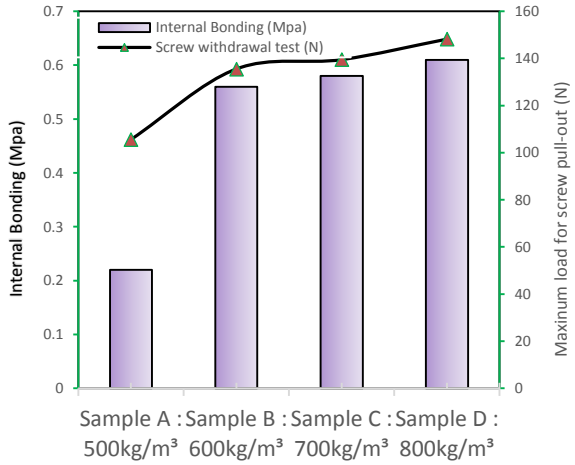


**Figure 3** Effect of density on internal bonding and screw test

Low density of particleboard causes the internal bonding strength to reduce because the amount of matrix in the particleboard had reduced. The loss of matrix to wet the particles for bonding reduced the strength of the board [28].

### 3.1.4 Screw Withdrawal Test

Figure 3 shows the screw strength of the particleboards at different density. Overall, sample D has the highest screw holding ability. The experiment shows that panel density has a significant impact on the performance of the screw holding power [15]. The screw holding ability increased with the density [25, 29]. Sample D had better performance on screw holding ability compared to the particleboards with the lower density. This is due to the particleboard with higher density had formed a good structure order. The higher compatibility caused the sago particles to bond well with the UF matrix in a more effective way and had increased the bonding strength between the particles and matrix. The efficient interfacial bonding between the particles indirectly increased the compatibility and the ability of the boards to hold the screw securely when the screw was being pulled out [30]. It was discovered that the screw withdrawal resistance is strongly associated with the board density. As the density increased, the particles and matrix loading had strengthened the mechanical performance of the board [30].

The screw withdrawal are affected by other factors such as screw geometry, depth of penetration into

particleboards, particle grain direction, moisture content, raw material and rate of loading during test [15, 29,30].

### 3.1.5 Young's Modules (MOE)

The MOE result for each of the particleboard with different density is summarized in Figure 4. Based on the result, the MOE increased linearly with particleboard density. The increase in strength properties is associated with higher compaction ratio at higher density [25]. Sample D has the highest MOE while sample A shows the least. According to Jani and Kamal (2012), the higher MOE will lead to higher stiffness of the boards [30]. Particleboards tend to be brittle when the MOE value is higher and tend to be ductile or flexible when the value is low.

Jani and Kamal (2012) have the same view on increased the board density had caused the addition of resin into the board increased the MOE and made the board more brittle [30]. This is expected to influence the overall stiffness of the board. The higher degree of compaction for the particleboard will create well-bonded boards and resulted in harder panels [15].

Low density particleboard has reduced MOE strength since the raw materials at low quality in bonding and bonding at less compacted condition.

MOE is also influenced by factors like fibre composition, fibre morphology, fibre dispersion, distribution offibre in the whole volume of the material and fibre-matrix interface quality in the whole composite [31].

### 3.1.6 Tensile Strength

Figure 4 showed the density had great influence on the tensile strength. The tensile strength increased with density of the particleboard from 500 kg/m$^3$ to 800kg/m$^3$. Nwanonenyi *et al*. (2013) also reported that increased density of the composite lead to increase in tensile strength [32].

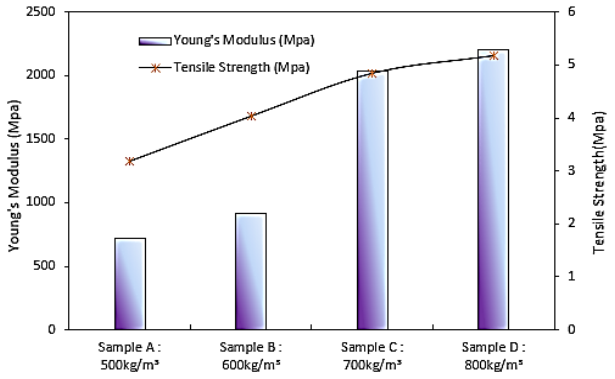


**Figure 4** Effect of density on Young's modulus and tensile strength

Sample D had the highest tensile strength performance while sample A had the least. When density increased, the compatibility between the fibre and matrix increased and led to an increase in the strength of composite. When the density increased, it was found that the average pore size decreased. The number of pores per unit area increased slightly and the pores became less interconnected. However, lower density particleboards have high level of porosity. The pores were exerted by stress-concentrating and reduced the load bearing [33]. The higher compatibility caused the fibre to transfer the stress between the matrix more effectively. Therefore, the particleboards had better stress concentration and managed to withstand the higher stress while being stretched or pulled before failure.

Cracking easily occurred on particleboards with lower compatibility. This is due to the closely spaced particles, causing high strain magnifications between the particles. As the strain increases, cracking occurs in the bundles oriented at other angles to the tensile axis as predicted from the orientation. Shear cracking and resin fracture had caused the specimen fail as the load increased [31].

### 3.1.7 Impact Strength

The performance of UF-sago particleboard with different densities is shown in Figure 5. The best performance of impact strength was achieved by sample C while sample A achieved the least. Increasing the particleboard density increase the impact strength up to a certain limit then drops after that. Sample C have perfect compatibility to achieve the highest impact strength. This is due to voids within the composite were filled with compatible particles and matrix which created a good interconnection and absorbed energy more efficiently during test. The improvement in impact strength could be due to the amount of matrix that allowed the applied stress to be transferred more effectively due to increment in total fibre surface in contact with matrix.

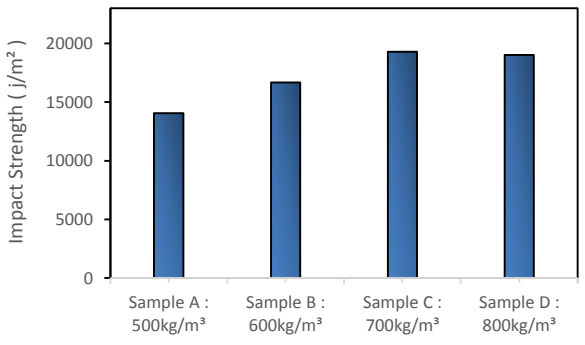


**Figure 5** Effect of density on impact strength

Weak interfacial bonding of natural particles was mainly due to incompatibility between hydrophobic matrix and hydrophilic fibre. It was found that some of

the particleboards had low impact toughness due to ineffective energy dissipation mechanism at the interface. Irregular hole size could be attributed to voids and air entrapment, which led to poor interface between the particles and matrix with internal defect in composite. Part of the low impact strength was also attributed to poor fibre dispersion, which resulted in weak interfacial bonding between the fibre and matrix that consequently, created potential sites for crack growth.

The impact properties of composite materials are directly related to the nature of the constituent materials, fibre-matrix interface, construction and geometry of the composites and the test conditions [34].

## 3.2 Physical Properties

### 3.2.1 Water Absorption (WA)

Figure 6 showed the effect of density on water absorption. The rapid uptake of water over the first 2 hours due to the hydrophilic natural of the cellulosic materials, enabling the composites to take up a high amount of water. Water absorption increased with the immersion time.

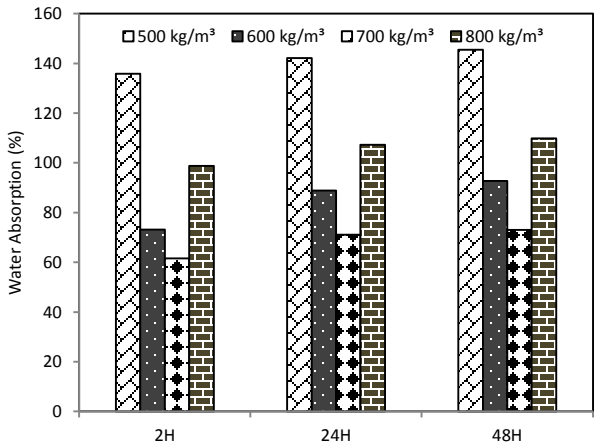


**Figure 6** Effect of density on water absorption

The highest water absorption was obtained in sample A while sample C had the least. The higher percentage of water absorption in sample A is attributed to loosen packing in particleboard and created void in the boards which allowed more water intake compared to sample C [23]. In low density particleboard, the highly porous structure of the board allows water to penetrate into the board and increase the water uptake [30]. This had caused more water absorption inlow density particleboard than the higher density particleboard due to the presence of voids inside the particleboard, leading to higher water absorption [16]. The formation of micro-channels, which contribute to the higher water absorption and provide a way for water to pass through pores on the surface of the particles. This had caused the water entered into the particleboard easily through the pores and absorbed by polar OH groups of sago particles. This leads to a rise of water absorption and weight gain in the particleboard. Water absorption behaviour of natural fibres also depends on free hydroxyl groups present in cellulose and hemicelluloses, which are accessible by water [35].

Sample C was compressed in good order with high compatibility and reduced the voids content which caused the least water uptake. This shows that the packing and arrangement of particles limit the absorption of moisture into the particleboard, because the voids have been filled up during the formation of composite [35]. Particleboard with higher density is attributed to the heterogeneous nature of the particles which had enhanced bonding and filling of void spaces in the boards [23]. This could be due to the intermolecular hydrogen bonds that may restrain water acceptability in the denser panel [28]. Higher compaction ratio implies that more compressive deformation has been imparted onto the particles during hot pressing. Particles were under greater compressive set and caused the void formation to be reduced. Hence, lessening the water absorption property [30].

Sample D had the higher water absorption compared to Sample C because more water absorpted by its large volume of particles which is to equalize the target board density [36,37].Board that are not properly bonded with UF and particles will expands further and allow the water penetration and absorption increased when submerged in water [36,37].

Based on the report by Jani and Kamal (2012), hygroscopic expansion can be affected by various factors of the resin such as the monomer, polymerization rate, cross-linking and pore size of the polymer network, bond strength, interaction between polymer and water, filler and resin filler interface [30].

### 3.2.2 Thickness Swelling (TS)

Figure 7 shows the thickness swelling at different density exposure to atmosphere with immersion time of particleboard. The highest thickness swelling (TS) was found in sample C. Sample B had the lowest thickness swelling compared to the other specimens.

The presence of more irregular void in sample A had enhanced water absorption and thickness swelling [23]. Uncompacted particleboard has developed a lot of voids in between the particle during the formation. Thus, this will increase the number of micro voids caused by the large amount of poor bonded area between the hydrophilic filler and the hydrophobic matrix polymer and weaken the particles/matrix adhesion in nature [38].

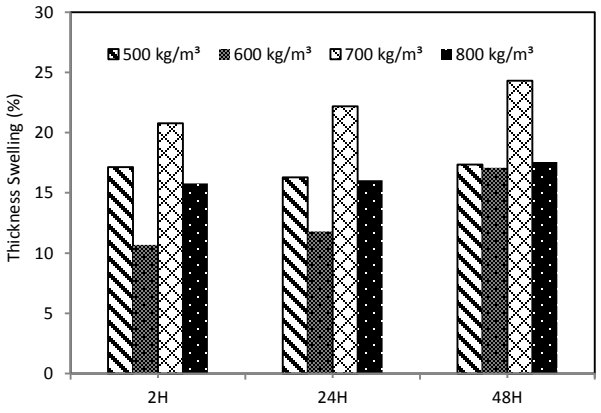


**Figure 7** Effect of density on thickness swelling

## 3.3 Thermal Properties

### *3.3.1 Thermogravimetric Analysis (TGA)*

Figure 8 shows the TGA curves of different densities and the results obtained with different density analysis are tabulated in Table 1. All the specimens showed a single stage decomposition reaction, where they are decomposed into three steps, which are water absorption, volatile and char. Increasing density not only improve the resistance of particle boards to thermal degradation but also alters their pyrolysis route and thus increasing the char produced.

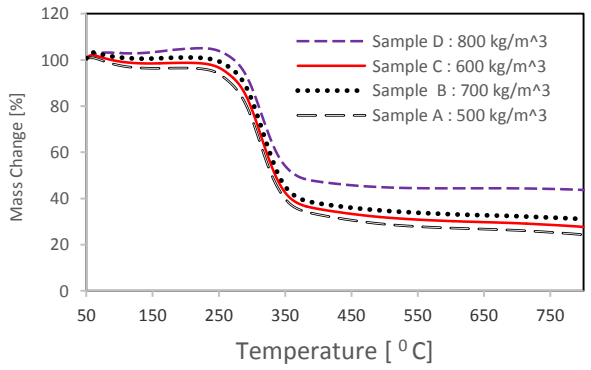


**Figure 8** Sago/UF sample with different density analysis by TGA

**Table 1** Results for Sago / UF sample with different density analysis by TGA

| Sample. | Temperature Peak (◦ C) | Mass loss (%) | Residues (%) |
|---|---|---|---|
| A: 500 kg/m³ | 86.79 ◦ C | 3.88% | 25.24% |
| | 310.62 ◦ C | 70.88% | |
| B: 600 kg/m³ | 71.03 ◦ C | 3.56% | 27.38% |
| | 308.77 ◦ C | 69.06% | |
| C: 700 kg/m³ | 69.28 ◦ C | 3.12% | 28.58% |
| | 309.16 ◦ C | 68.30% | |
| D: 800 kg/m³ | 63.52 ◦ C | 2.76% | 30.63% |
| | 311.64 ◦ C | 66.61% | |

The TGA curve shows that all the specimens have the same characteristics where a change in mass for all specimens were observed at temperatures from 50oC to 200oC. This is because the specimens have ahigher moisture content at this stage [39]. Sample D has the highest compatibility in structure because it is associated with the highest level of the curve compared to Sample A. Sample A has the least density in structure order [40]. The results shows that better thermal stability can be achieved with a denser packing.

The decomposition peak for all specimens occurred in between 308°C and 311°C. Based on the thermal behaviour of the particle board, a hot pressing temperature of 160°C is suitable for the sago fibres to react with UF without thermal decomposition. Degradation of hemicellulose, cellulose and lignin can be observed at temperatures between 245°C – 364°C, 241°C - 354°C, 243°C-350°C with mass loss of 70.88% (sample A), 69.06% (sample B), 68.30% (sample C) and 66.61% (sample D). Degradation continues slowly until a fixed carbon content at 800°C. The range of decomposition temperature decreased with increasing density which may be caused by a more homogeneous dispersion of fibres and UF in the particle board.

Sample D have the least mass loss with 2.76% at 63.52°C because it has the lowest moisture content of sago fibre incorporated in the composite [41]. Higher compaction facilitates bonding and resistance to moisture trapping on specimen which resulted in reducing the void between the particles. Sample D undergoes degradation with a mass loss of 66.61% at 311.64°C. The specimen will degrade further until 30.63% of char is formed. The decomposition reaction kinetics can be significantly altered with a denser packing. A denser packing can also inhibit the diffusion of evolved gases through the sample [40]. Thermal stability can be improved with good compatibility because of low migration characteristics and homogeneous dispersion of the particles and matrix [42].

Sample A initially has the highest weight loss which is about 3.88% at 86.79°C due to the higher moisture content within the particleboard and the presence of hemicellulose had improved the moisture absorption in the composite [41,43,44]. The moisture in sample A start to evaporate earlier than other samples at around 54.67°C-220°C with a longer time and higher temperature [44]. The degradation of hemicelluloses, cellulose and lignin in the second region at 310.62°C with mass loss of 70.88% [43]. The specimen continues to degrade until a fixed carbon content with 25.24% of mass loss at 800°C is obtained. Char is formed when the specimen undergoes continuous degradation until a constant carbon content is obtained. The conductivity of a loosely packed specimen is low due to the fact that the air between the particles has poor conductivity.

Sample B and C were having the fixed carbon content with 27.38% and 28.58% respectively after the second stage of degradation.

### 3.3.2 Different Scanning Calorimetry (DSC)

The thermogram in Figure 9 shows the organic compound melt with decomposition [43]. Allthe specimens showed an endotherm peak between 50°C to 100°C which indicates a high amount of water molecules in Sago/UF particleboard [38]. Sample D and A have the higher amount of water molecule in the sago fibres compared with sample B and C. The higher amount of water molecules in sample A was due to low compatibility of the particleboard structure and trapped more moisture from the surrounding. Sample D had higher moisture was due to the higher amount of UF applied on the particleboard.

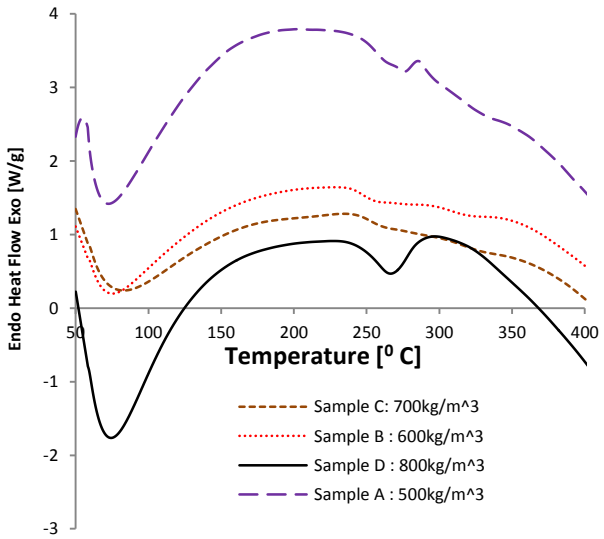


**Figure 9** Thermogram of Sago / UF sample with different density analysis by DSC

Generally, decomposition for sago fibre begin at 230°C-350°C and indicates a loss of amorphous structure of cell wall like hemicellulose, cellulose and some portion of lignin. The cellulose did not decompose until 340°C [44].

From the DSC thermogram, sample D showed a single endothermic peak at 265°C due to thermal decomposition of sago fibres [40]. Sample A and B exhibited two endothermic peaks which is at 260°C and 340°C for sample A and 260°C and 325°C for sample B. The double endothermic peaks obtained in DSC thermogram were due to the thermal decomposition of Sago fibres and filled with UF [45]. This observation can be explained on the basis of prominent changes like evapoaration of moisture, decomposition of hemicellulose, cellulose and lignin that occur in the structure and morphology of sago fibre components [40]. The second exotherm peak at 287°C may be due to further pyrolysis of the remaining cell wall structure [44].

The thermogram shows the area under the curve peak for sample A is smaller compared to sample D. It had shown that sample A was less compact in the structure and easy to cure compared with sample D [40]. This may be due to the particleboard which was fabricated with smaller amount of UF and sago particles hence having a better curing properties. The addition of fibre to the UF system results in barriers to the UF cure. The UF oligomers molecules have unrestricted space to polymerize for complete cure and increased the enthalpy reaction [47].

According to the thermogram, the higher melting temperature of starch was found on the higher density board. Based on the thermogram, the peak of melting for sago starch was fall at 72.66°C for sample A, 73°C for sample B, 74°C for sample C and 76°C for sample D [47].It was attributed to the structure perfection or degree of crystallinity at this stage [46]. The higher density of particleboard has higher melting temperature due to the crosslinking reaction with epichlorohydin and leads to better interaction between starch and particles in panel manufactured. The reinforcing of starch granules through crosslinking reaction with epichlorohydrin contributes to higher strength of panel where more heat is required for melting process to complete [48]. As a result, higher density particleboard had a higher melting enthalpy. Sample A and D showed that UF have crucial reaction during the thermal degradation at 274°C and 267°C respective. The higher temperature had caused the chain rupture in UF molecule [49].

## 4.0 CONCLUSION

The results show that increasing the density will affect the mechanical, thermal stability and physical properties of a particleboard. It can be seen that the compatibility of the particleboard has a significant effect on the performance of a board. Based on the result, particleboards with 700 kg/m$^3$ and 800 kg/m$^3$ met MOE and IB requirement of American National Standard A208.1-2009 for wood particleboard and fulfilled the industrial purpose. Particleboard with 600 kg/m$^3$ only managed to meet the IB requirement of the American standard. The physical properties can be improved by mixing the raw material with wax to prevent water from penetrating into the board for furniture application. 500 kg/m$^3$ particleboard has better curing properties due to the small amount of fibres and UF applied on the fabrication. 800 kg/m$^3$ particleboard had the smallest weight loss of moisture content in the board and it has better thermal properties.

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