

# Water Absorption and Thickness Swelling Behavior of Sago Particles Urea Formaldehyde Particleboard

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**Abstract:** This paper focused on sago particles with adhesive of low emission urea formaldehyde (UF) resin containing 51.5% solid content. The fabrication and testing method are based on Japanese Industrial Standard A 5908 standard. The production of single-layer particleboards using the sago particles has been established at targeted density of 600kg/m<sup>3</sup>. Fibre weight fractions of 90%, 85%, 80%, 75% and 70% and different sizes of particles were used in the fabrication of sago-UF composite boards. All the panels are tested for physical test properties which is water absorption and thickness swelling. The combination of sago particles with UF panels can be utilized for general indoor application purposes such as furniture manufacturing. The result showed that sago can be an alternative raw material in the manufacture of particleboards.

**Keywords:** sago particles, particleboards, physical properties, Urea-Formaldehyde, Water absorption, Thickness swelling.

## 1. Introduction

With advances in technology and increase in the global population, the demand for wood in the forest product industry has grown over the years. In addition, the application of wood in new areas had also caused a significant pressure on the current standing forest resources. This has generated the necessity for people in the forest industry and scientists studying in this field to find alternative biomasses or raw materials. Alternative fibers such as agro fibers will play an important role in the wood fiber supply/demand map of the future [1]. Recently, natural fiber plastic composites gained increasing interest among scientists due to the desirable properties of natural fibers and their broader application [2]. Physical properties like water absorption of wood is great importance, especially in the structural wood. However, wood undergoes changes in its moisture content all the time and the water absorption properties significantly affect the mechanical properties of a product [3].

Water absorbed in polymers is generally divided into free water and bound water. Water molecules that are contained in the free volume of polymer are relatively free to travel through the micro voids and holes and identified as free water, whereas, water molecules that are dispersed in the polymer-matrix and attached to the polar groups of a polymer are known as bound water. Water can penetrate into the cellulose network of the fiber and into the capillaries and spaces between the fibrils and less bound areas of the fibrils. Water may attach itself by chemical links to group in the cellulose molecules. The rigidity of the cellulose structure is destroyed by the water molecules in the cellulose network structure in which water acts as a plasticiser and it permits cellulose molecules to move freely. Consequently the mass of cellulose is softened and can change the dimensions of the fibre easily [10].

The water absorption rate of a composite is influenced by the factors such as; type of fibre and matrix, atmosphere environment like temperature and humidity, water

distribution within the composite and reaction between water and matrix, porosity and volume fraction of fibers [6].

To improve the stability, understanding the water absorption on the particleboard will be the main factor to be evaluated on the dimensional and physical change [4].

## 2. Material and Methods

### 2.1 Sago Preparation

The Sago particles were obtained from Mukah in Sarawak, Malaysia. The particles went through the sieving process for separation of particle size. During this experiment, 0.60mm, 1.18mm and 2.00mm 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 an oven at 105°C for 24 hours to achieve moisture content of less than 5% before undergoing the fabrication process. Figure 1 shows the sieving vibrator used in the sieving process. The outputs were cross checked by using the HIROX KH-8700 microscope.



Figure 1: Sieving Vibrator

**2.2 Board Parameters:**

The target density was set at 600kg/m<sup>3</sup>. The preparation of the board depends on the required sieving size and weight fraction. The parameters used in fabricating the particleboards are shown in Table 1. Urea formaldehyde (UF) resin at 51.5% that serves as particles binder was obtained from Hexzachem Sarawak Sdn. Bhd and used as a binder together with 1% NH<sub>4</sub>Cl solution that acts as a hardener.

**Table 1: parameter for particleboard**

Raw material	Sago particles
	0.60mm, 1.18mm & 2.00mm
Target board density	600 kg/m <sup>3</sup>
UF resin	Solid content 51.5%
Hardener (NH <sub>4</sub> Cl)	1%
UF Appearance	White & opaque
Viscosity@30 <sup>o</sup> C	168CPS
Specific Gravity@ 30 <sup>o</sup> C	1.198
PH@ 25 <sup>o</sup> C	8.0
Solid Content hrs.@105 <sup>o</sup> C)	51.5%
Gel Time@100 <sup>o</sup> C	41sec
Free Formaldehyde	1.23%
Water Tolerance@30 <sup>o</sup> C	197%
Free Formaldehyde	1.23%
Board Size (cm)	30 x 30 x 1

**2.3 Particles Board Fabrication**

The sago particles were weighed based on the desired weight and were directly placed into the mixing drum which was equipped with an airless spray gun. The core particles were mixed by spraying them with urea-formaldehyde and hardener (NH<sub>4</sub>Cl) for 5 minutes to achieve a homogeneous distribution of adhesives on them. After the blending process, the sago particles were spread evenly into the 30cmX 30cm wooden mould by using a 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<sup>o</sup>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 the humidity of 65±5% for two days curing process. The main purpose of the curing process is to stabilize the particleboards before they undergo property evaluation later on.

**2.4 Testing Method**

The determination of 2 hours and 24 hours water absorption (WA) and thickness swelling (TS) tests were performed according to ASTM D-1037. Water absorption tests were conducted by immersing the Sago-UF specimens in a de-ionised water bath at 25<sup>o</sup>C for different time durations. After going through the 2 hours, 24 hours, 48 hours, and 72 hours immersion process, the specimens were taken out from water and the surfaces were dried using a clean dry cloth. The specimens were reweighed to the nearest 0.1mg within 1 min of removing them from the water. The specimens were weighed regularly at 2 hours, 24 hours, 48 hours and up to 72 hours exposure. The water absorption of each specimen was calculated by the weight difference. The water absorption and thickness swelling of each specimen were prepared with the dimension of 50mm X 50mm X 10mm.

**Water absorption (%)**

W<sub>i</sub> = initial weight  
W<sub>f</sub> = final weight

**Water absorption (%) =**

$$\frac{W_f - W_i}{W_i} \times 100\% \dots\dots\dots \text{Equation 1}$$

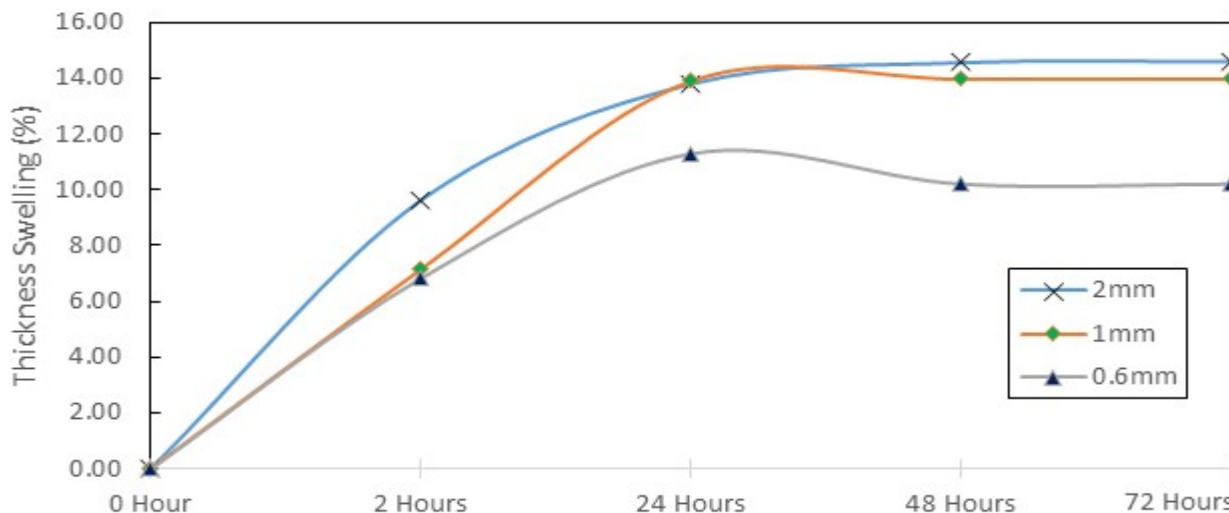
**Thickness swelling (%)**

T<sub>i</sub> = initial thickness  
T<sub>f</sub> = final thickness

**Thickness swelling (%) =**

$$\frac{T_f - T_i}{T_i} \times 100\% \dots\dots\dots \text{Equation 2}$$

**3. Results and Discussion**



**Figure 2: Thickness Swelling Vs. Soaking Time**

Figure 2 shows thickness swelling (TS) of the particleboards were affected when the sago particles size was increased. Thickness swelling trend increased with the immersion time and become constant after 24 hours.

Particleboard with 0.6mm size achieved the lowest thickness swelling. This is due to the low diffusion rate in a particleboard with higher compaction that had reduced the porosity and thus lowered the capacity of a particleboard in absorbing water due to its limited surface area. Higher compaction reduced water penetration into the particleboard and consequently, the water needs a longer time to diffuse into the particles and panel.

Particleboards with 2mm particles size had the highest TS value at the beginning until 24 hours where the water increment rate started to slow down. During the soaking process, the TS value increased again because the particles had expanded and some particles were released from the particleboards.

In addition, TS is also influenced by the geometry of particles, their structure and the presence of many voids in the boards that allow internal swelling as well [5].

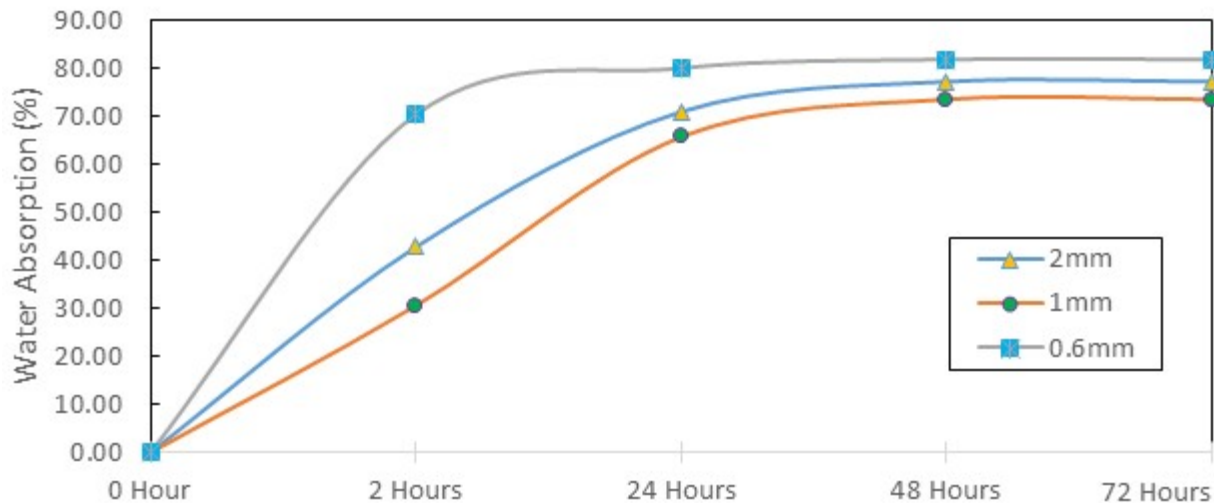


Figure 3: Water absorption vs. soaking time

Figure 3 shows the results of water absorption (WA) of the particleboards against the soaking time. There were two-step processes for the water uptake patterns. During the first two hours, more than half of the final absorbed water occurred. This was followed by a period of very slow and consistent water uptake [3]. The higher initial water absorption rate can be explained by the diffusion phenomenon, like a fluid migration, where the water spreads itself through the capillaries, vessels and cellular walls of the sago particles. Two forms of water up-take patterns were present: interstitial water and bound water. The interstitial water is contained in the cellular cavities and bound water is retained in the cellular walls. The rate of water absorption depends on the difference between the saturation water content and the water content at a given time, which is called the driving force. The moisture diffusion into the particles takes place because of moisture gradient between the surface and the centre. As sorption proceeds, the water content increases, diminishing the driving force and consequently the absorption rate. Generally, the interstitial water molecules are relatively weaker than the bound water molecules, thus, water will migrate from the more concentrated medium towards the less concentrated one.

The size and shape of the individual particle furnish are significant factors that influence the water absorption process. The water absorption rate increases with the chip

particle thickness because in thinner particles, the maximum over pressure in the centre of a material is higher and the distance for transporting the water from the surface is halved compared with the bigger size and the main pressure release occurs in the longitudinal direction. When the longitudinal and latitudinal dimension is doubled, the maximum over pressure increases by a factor of more than two because of the larger length of longitudinal and latitudinal flow necessary for water absorption to be stable. The total time is longer in order to achieve the equal volumes, a smaller particles will achieve faster than the bigger one due to the highest resistance to flow in the thickness direction. The ability of composites to absorb water is an indicator of their porosity[6]. 1mm particle had the least porosity when applied in composite. As a result, it had the least water absorption compared to the smallest and biggest particles. During the particleboard fabrication, small size of particles that had bigger spaces between each other caused the water molecules to easily substitute the spaces in between. On the other hand, 2mm particles having the same problem just slightly different than 0.6mm. 1mm particles were the suitable size for the particleboard fabrication and the spaces between the particles made it difficult for the water molecules to penetrate into the particleboard. 1mm particles showed good inter-particle bonding between the particles and matrix during the hot-press process and had reduced the porosity of the boards which made the boards to become water repellent.

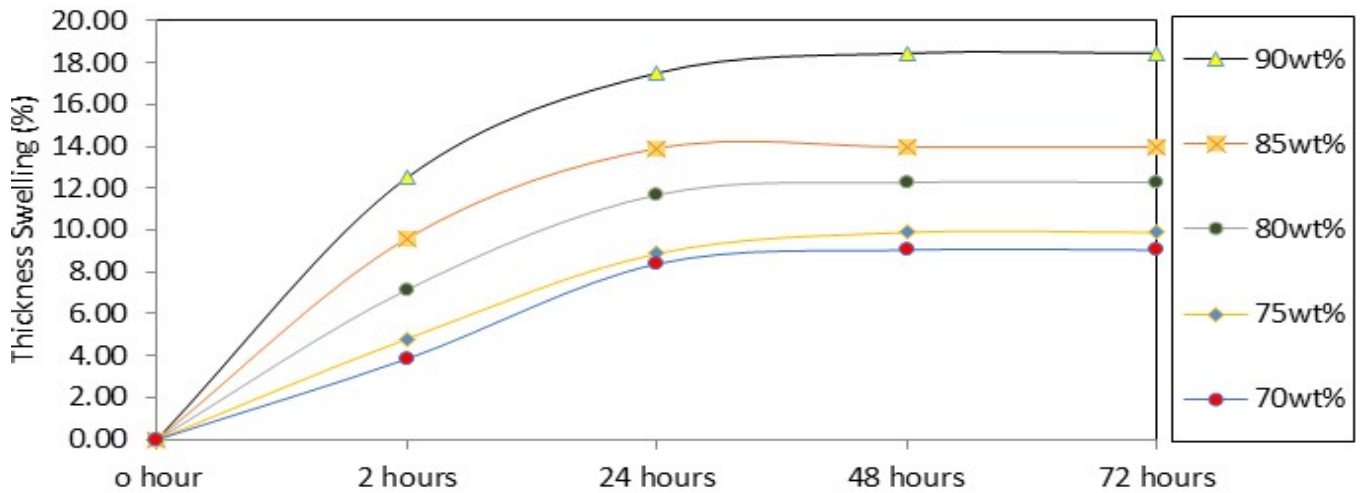


Figure 4: Thickness swelling vs. Soaking time

Figure 4 shows the results of TS of particleboards affected by the weight fractions. The results indicated that a decrease in the weight fraction of fiber (increase in UF content) affect the thickness swelling [5]. This is because sago was less repellent to water as more resins were incorporated into the board [7]. The thickness swelling could be affected by the bonding quality between the particles and the adhesive properties [4]. An increase in adhesive creates better bonding quality as compared with small amount of UF.

The presence of sago bark in the particleboards resulted in higher water resistance. This is because the presence of

polyphenolic extractives in the barks reacted with the UF and improved the water resistance properties [8].

The high values obtained from the TS tests were due to the high percentage of highly absorbent particles in the panels. The particles were very short and constituted a high percentage of total fiber content, thus, creating a very large and highly absorbent surface area. The highly porous structure of the board allowed the water molecules to penetrate into the board and increased the water uptake, resulting in high water absorption and caused the board to swell and subsequently led to an increase in the TS [9].

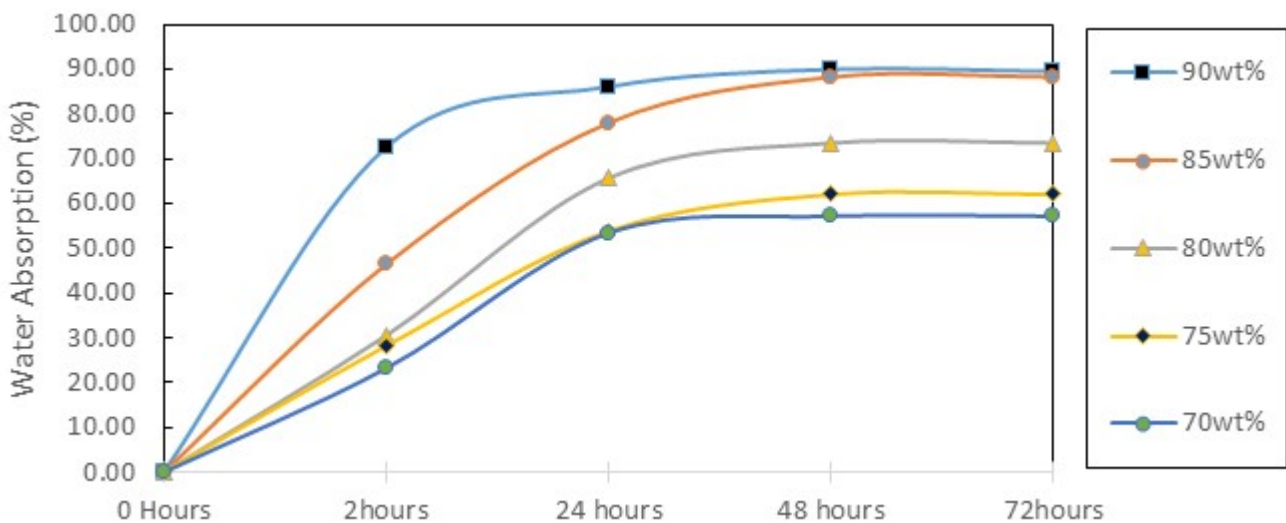


Figure 5: Water absorption vs. Soaking time

Figure 5 shows the results of water absorption (WA) of particleboards which is affected by the weight fraction. The results show that the resin content has a significant effect on the water absorption. The trend of the water uptake process was linear in the beginning, then slowed down and reached saturation after prolonged time [10]. The long term water absorption of Sago-UF particleboard maintained relatively stable dimensions after 72 hours [4]. Sago-UF particleboards with 70wt% had better qualities than the 90wt%. The addition of UF in the particleboard, caused the formation of hydrogen bonds, increased the water binding sites and reduced the particleboard's capacity of absorbing water [8]. Water absorption decreased with resin content due to the

chemical components in the resin that is capable of cross-linking with the hydroxyl group of the fibers, hence reducing the hygroscopicity of the boards. Hygroscopic expansion can be affected by various factors of the resin such as the monomer, the polymerization rates, the cross-linking and pore size of the polymer network, the bond strength, the interaction between polymer and water, the filler and the resin-filler interface [9].

Water absorption increased as the particles loading increased and this can be explained by the theory of void over volume of the board where the particles were not fully bound by the UF and hydroxyl properties by the fiber. Higher fibre loaded

samples would be expected to contain a greater diffusivity due to higher cellulose content[10].The hydrophilic character of sago particles is responsible for the water absorption in the particleboard, therefore, higher content in fiber lead to a higher amount of water absorbed. Generally, water absorption increases with immersion time until equilibrium condition is reached. When the particles content are increased in the particleboard, the number of free OH group of sago cellulose also increases. Hence, the water absorption increases[12]. Besides, sago particles consist of strong hydrophilic cellulose in an amorphous matrix of hemicelluloses and lignin; the main reason for water absorption by composite materials. This may be attributed to the fact that sago particles is extremely hydrophilic in nature due to the presence of the hydrophilic hydroxyl group of cellulose, hemicelluloses and lignin that is responsible for water absorption [13]. The 90wt% of sago particles were incomplete encapsulation of UF and probable occurrence of sago particles aggregates and lead to the high penetration ability due to the porosity.

The hydrophilic sago particles/fiber swells when the composite is exposed to moisture. As a result of fibre swelling, micro cracking of the brittle thermosetting resin occurs. The high cellulose content in sago fibre further contributes to more water penetrating into the interface, through the micro cracks induced by swelling of fibers, creating swelling stresses leading to composite failure. The water molecules actively attack the interface, resulting in deboning of fibre and matrix[10].

#### 4. Conclusions

This study investigated the effect of weight fraction and particles size on the water absorption and thickness swelling test. 0.6mm and 2mm particle sizes were shown to have poor adhesion with the UF matrix, giving rise to water absorption and thickness swelling. The results show that the resin content has significant effects on the water adsorption and thickness swelling expansion. Water resistance can be reduced using three different methods: by adding wax (hydrophobic materials) into the adhesive during the manufacturing process, reducing the density of the particleboard to decrease the spring back effect and adding more barks to improve the water resistance. This study shows that sago particles can be utilized as a raw material in particleboard manufacturing. The findings show that the new application for sago may potentially reduce the pressure on the forest resources as well as providing additional income to the farmer in Mukah Sarawak.

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#### Author Profile



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