# Mechanical and Physical Properties of Low Density Kenaf Core Particleboards Bonded with Different Resins

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**Abstract**

Single layer kenaf (*Hibiscus cannabinus*) core particleboards bonded with urea formaldehyde (UF), phenol formaldehyde (PF) and polymeric 4,4-methyl phenylmethane di-isocyanate (PMDI) resins were manufactured. The boards were fabricated with three different densities i.e 350 kg/m$^3$, 450 kg/m$^3$ and 550 kg/m$^3$. Each type of the resin used was sprayed at three different resin loadings on the kenaf core particles. The boards produced was evaluated for its modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB), screw withdrawal (SWD), water absorption (WA) and thickness swelling (TS) in accordance with the British Standards. The study revealed that boards with higher resin contents gave higher MOR, MOE, internal bond and screw withdrawal and also improved the water absorption and thickness swelling. Similar trend was also observed from boards with higher densities. It is concluded that the boards with the density of 550 kg/m$^3$ were able to fulfill the British Standard specifications.

**Keywords**: *Hibiscus cannabinus*; density; urea formaldehyde; phenol formaldehyde; polymeric 4,4-methyl phenylmethane di-isocyanate

# 1. INTRODUCTION

Nowadays, awareness among people of wood-based industry to find alternative resources in order to ensure continuous supply of materials from the forests for production of composites seems increased due to the worldwide shortage of forest resources [1]. Numbers of alternative resources which are mainly come from fast-growing species such as *Acacia mangium*, *Shorea macrophylla*, [2,3,4,5] kenaf [6] and bamboo [7,8,9] as well as lesser-known or under-utilised species, and lower grade timbers [10] have been discovered to reduce the effect of the shortage. Among the alternative resources, crop like kenaf seems more considerable for that purpose because of its fibres, especially the outer part which is low cost, low density, high toughness, suitable for recycling, acceptable strength properties and biodegradability [11]. In Malaysia, Kenaf is still new and promotion to encourage acceptance upon it, is given fairly great. Kenaf is a warm season annual fibre crop closely related to cotton (*Gossypium hirsutum L., Malvaceae*) and okra (*Abelmoschus esculentus L., Malvaceae*) [12]. Two of the potentials that this crop possesses are the ability to grow fast as well as two types of fibres it has i.e bast (outer part) and core (inner part) which can be utilized as components of paper products, building materials, absorbents, textiles and livestock feed [13]. Kenaf is able to reach a height of 3 to 5 metre within 3 to 5 months, depending on the environment condition of the place it is planted. Kenaf is able to supply between 12 and 25 t/ha of biomass annually, when it is planted under warm and wet conditions [13].

Kenaf bast has obtained greater attention than kenaf core. This is probably due to its mechanical properties which is greater than the core [11, 33]. The kenaf core is light and porous, having a bulk density of 0.10-0.20 g/cm$^3$. It can be easily being crushed into very light-weight particles. The cellulose and lignin contents of kenaf core are quite similar (between 31-33% and 23-27% respectively) to wood but the hemicellulose is higher [12]. It is discovered that only kenaf bast fibres are largely used in paper industry, whereas systematic information on extensive utilization of kenaf core in composite industry is still limited. Therefore, researches were undertaken to reveal the potential that the core has such as using kenaf core to make insulation composites [13, 14], medium-density particleboards [15, 16], fire retardant-treated particleboards [5,17,18,19] and polymer composite [20]. Hence, a study was conducted to enhance the utilization of kenaf core by helping in promoting the material as an input for the production of particleboard. This study was to investigate the influence of resin content, fibre content and resin type to the mechanical and physical properties of low density kenaf core particleboard.

## 2. MATERIALS AND METHODS

### 2.1 Kenaf

Four month old kenaf stalks of G-4 variety were obtained from the Kenaf Research Plot of MARDI Serdang, Selangor, Malaysia.

### 2.2 Binders

Urea formaldehyde (UF) resin at 64% solid content and phenol formaldehyde (PF) of 51% solid content were obtained from Dynea (M) Sdn. Bhd, Senawang, Negeri Sembilan, Malaysia. The polymeric 4,4-methyl phenylmethane di-isocyanate (PMDI) was supplied by Cosmo Polyurethane (M) Sdn. Bhd, Kuala Lumpur, Malaysia. Polymeric 4,4-methyl phenylmethane di-isocyanate (PMDI) was chosen as one of the binders because it releases no formaldehyde [21].

### 2.3 Preparation of Kenaf Particles

Kenaf core was separated from the bast and bark using kenaf decorticating machine. The separated kenaf core is in chip form. Then the kenaf core chips were flaked to a particle size of between 2-3 mm using Pallmann PHT 120/430 knife ring flaker. The particles were then dried in an oven at a temperature of $70^{0}$C for two days to achieve 5% moisture content (MC).

**Figure 1**: The kenaf decorticating machine

### 2.4 Resin Addition Process

The kenaf core particles were mixed with the resins separately using a blender machine. Three percentages of resin loadings used, i.e. 8%, 10% and 12% for UF, 7%, 9% and 11% for PF, and 3%, 5% and 7% for PMDI respectively. Each of the resin loading was based on the oven dry weight of the kenaf core particles. The particles and the resins were mixed approximately in the blender for 5 minutes to ensure that the particles are evenly mixed with the resins.

**Figure 2**: The blender machine

## 2.5 Board Making

After the mixing process, the kenaf particles were removed from the mixer and were scattered in a square-shaped former with a dimension of 340 x 340 mm, which was first placed on a caul plate covered with a teflon fibre sheet. The furnish of kenaf particles + resin was pre-pressed in the cold press at a pressure of 35 kg/cm$^2$ and subsequently pressed in the hot press machine model Taihei to 12 mm thickness at a temperature of 170$^0$C for 6 min. For PF and PMDI board, the hot press temperature was 190$^0$C. And then, the particleboards were exposed to the surrounding to cool them down and encourage curing of the resin. Three targeted board densities were produced, i.e. 350 kg/m$^3$, 450 kg/m$^3$ and 550 kg/m$^3$. Five replicates were prepared for each density. The description of the particleboards is summarized in Table 1.

**Figure 3**: The hot press

## 2.6 Testing Procedures

All samples were kept in a conditioning room which was set at a temperature of 20 ±2$^0$C and 65 ±5% RH for 3 days prior to the testing. The conditioning was to ensure that the resin in the particleboard have cured uniformly. The mechanical tests carried out for the samples were bending strength tests (MOR, MOE) [22], internal bond (IB) [23] and screw withdrawal tests at the face and edge sections of the boards [24]. The screw withdrawal test was conducted with 38mm-long steel screws. The tests were carried out using Instron Universal testing machine Model 4204. The dimensional stability of the board was also determined *via* water absorption and thickness swelling tests. The water absorption and thickness swelling were calculated after immersing the samples in the water at 20$^0$C for 24 h [25].

**Table 1:** Description of the manufactured particleboards

| | |
|---|---|
| Raw Material | Kenaf core particle (1-2 mm size) |
| Targeted board densities | 350 kg/m$^3$, 450 kg/m$^3$and 550 kg/m$^3$ |
| Board Size | (340 x 340 x 12) mm$^3$ |
| Adhesive | |
| UF resin | 8 %, 10 % and 12 % (w/w of oven dry kenaf particles) |
| PF resin | 7 %, 9 % and 11 % (w/w of oven dry kenaf particles) |
| PMDI resin | 3 %, 5 % and 7 % (w/w of oven dry kenaf particles) |
| Pressing temperature | 170$^0$C (UF), 190$^0$C (PF and PMDI) |
| Pressing time | 6 minutes |
| Symbols for different resins; | |
| UF350/8 | Urea formaldehyde resin at 350 kg/m$^3$ board density and at 8% UF loading |
| PF350/7 | Phenol formaldehyde resin at 350 kg/m$^3$ board density and at 7% PF loading |
| PMDI350/3 | PMDI resin at 350 kg/m$^3$ board density and at 3% PMDI loading |

## 3. RESULT AND DISCUSSION

### 3.1 Mechanical Properties

Figure 5 shows modulus of rupture (MOR) results of kenaf particleboards fabricated using different resins and densities. It was observed that the mean MOR values increased with the increase of resin loading for all resin type. These results showed that the presence of resin has significantly affected the bending strength positively. For all resin type, the highest mean MOR values were recorded from samples with the density of 550 kg/m$^3$. None of the samples with 350 kg/m$^3$ and 450 kg/m$^3$ have surpassed the standard requirement value. Density of a board is influenced by the amount of particles used to fabricate the board. The higher the density, the larger the amount of particles used. Larger amount of particles were expected to reduce voids between particles in the particleboards and enhance the resistance to rupture.

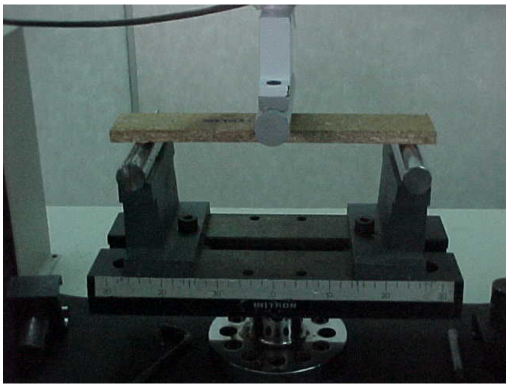

**Figure 4**: Bending strength test

Since the MOR indicates the ability of a specimen to withstand a transverse (bending) force perpendicular to its longitudinal axis [26], MOR results of the boards at higher density and resin contents are able to withstand such force. Influence of the wood particles on the board strength performances found clearly contributed to the MOR where a greater knead contents produced a greater MOR values as demonstrated in Figure 5. PMDI boards especially at 450 kg/m$^3$ and 550 kg/m$^3$ showed greater mean MOR values when compared to those bonded with UF and PF resins. This may due to the effectiveness of PMDI resin in covering the surfaces of the kenaf particles, hence enhancing chemical bonding through hydrogen bonds and polyurethane covalent bonds. In addition, the isocyanate groups of PMDI reacts with water in the kenaf particles and creating cross-linked polyureas for better mechanical bonding [27].

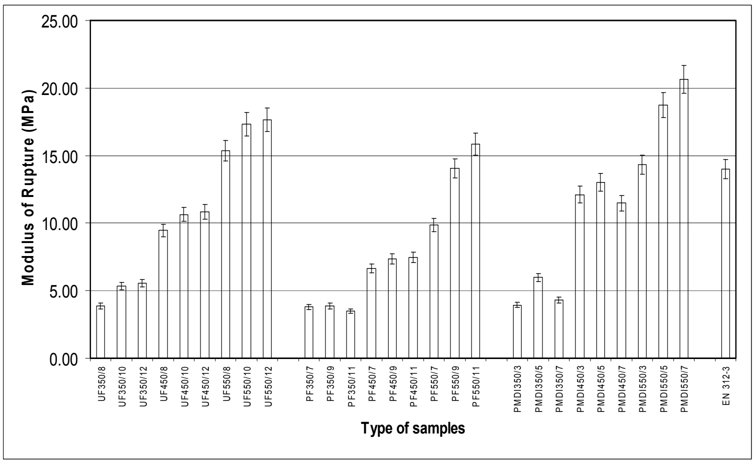


**Figure 5**: The MOR results of kenaf particleboards

In the case of MOE, the results were presented in the Figure 6. Modulus of elasticity (MOE) is the slope of the tangent line at the stress point of proportional limit. MOE is related to the stiffness of a board, and the higher the MOE the higher the stiffness. Generally, boards tend to brittle when the MOE value is high and tend to be ductile or flexible when the value is low [28]. From the mean MOR values presented in Figure 5, it can be seen that the value increased as the resin loading was increased too, especially for boards under the density of 550 kg/m$^3$. This indicates that the addition of resin into the board has increased MOE or makes the board to be more brittle. The results are tally with the previous studies [29]. The density of the board was also found to play a role in increasing the stiffness particularly for boards made of 550 kg/m$^3$ compared to those made of 450 kg/m$^3$ and 350 kg/m$^3$. This phenomenon seemed happened in every category of the fabricated boards. The inherent stiffness of the particles was expected to influence the overall stiffness of the boards positively. The mean MOE values of the board density at 550 kg/m$^3$ surpassed the minimum value of the EN 312-3 (1996) standard. PMDI-bonded boards exhibited tremendous mean MOE values in comparison with UF and PF-bonded boards, especially when the particle loading was high.

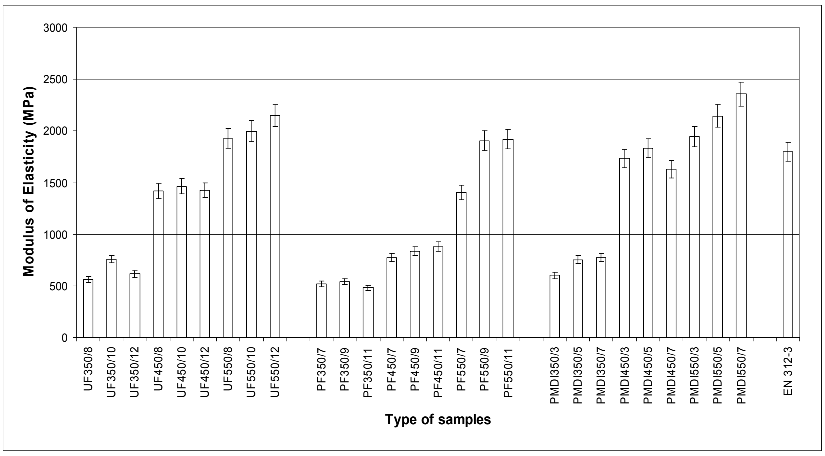


**Figure 6:** The MOE results of kenaf particleboards

Internal bond (IB) test was conducted to determine the interfacial bonding strength between fibre in the boards. The results (Figure 8) showed that the resins have significantly affected the mean IB values of the boards. The values were better when the loading of the resins was increased. This happened to all boards bonded with the three different resins. In general, mean IB values of the boards ~~at~~ bonded with UF resin at a loading of 12% were significantly higher than those bonded at resin loadings of 10% and 8% respectively. For PF-bonded boards, improvements though insignificant were recorded at the resin loadings of 11% and 9% respectively. This pattern was also happened to PMDI-bonded boards at the resin loadings of 7% and 5% respectively. The results indicate that higher amount of resin encourages stronger interfacial bonding between fibers in the boards, thus prolonged the ability for the boards to withstand the pulling force created through the test. By comparing between densities, it was seen that boards manufactured at 550 kg/m$^3$ was superior in internal bond (IB) strength, exceeding that of 450 kg/m$^3$ and 350 kg/m$^3$ board densities. The lower mean IB values found from the lower density boards were expected due to the existence of more voids in the boards compared to the higher density boards. The voids caused inefficiency of the inter-fiber bonding [30]. It is also interesting to highlight that almost all boards presented higher mean IB values than the minimum requirement value (0.4 MPa) of EN 312-3 (1996) as shown in Figure 8.

**Figure 7**: Internal bond test

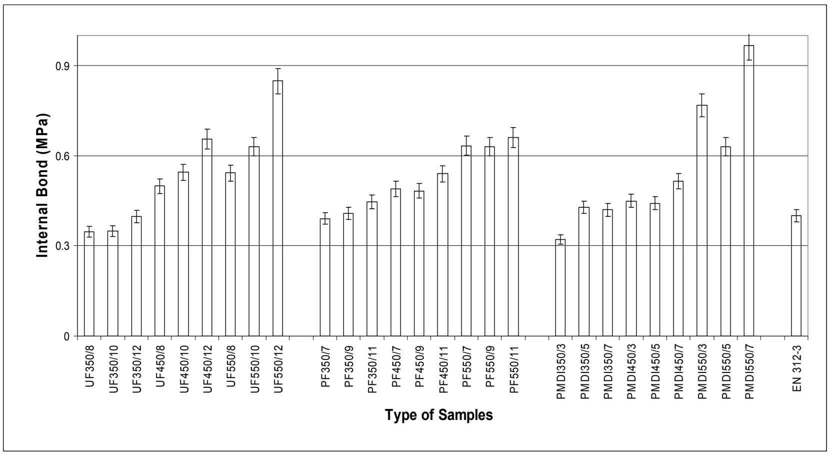


**Figure 8 :** The IB results of kenaf particleboards

The screw withdrawal (SW) test was conducted with the purpose to evaluate the screw holding strength on the face or edge sections of the boards. Figures 10 and 11 demonstrated the results of the screw withdrawal on the face and edge of the boards. The results revealed that the ability of the boards to hold the screw at face-wise was much better when the resin loading was higher. Like internal bond, the presence of greater amount of resin has improved the efficiency of the interfacial bonding of the boards. The efficient interfacial bonding between fibres, indirectly increased the ability of the boards to hold the screws pulled into them, hence increased the mean SW values. It happened to all of kenaf particleboards regardless to the resin type. UF-bonded boards recorded the best screw withdrawal values at the 10% and 12% UF loadings; however difference of the SW values of the two loadings were insignificant. Similar result patterns were also found for SW values of the edge section of the boards with regards to the resin type and board density. However, the edge section revealed lower screw withdrawal values compared to the face section. Meanwhile, for PF-bonded boards, there were no significant differences for mean SW values either at the face or edge sections with regards to the resin type, loading and board density. Nevertheless, for PMDI-bonded boards, the highest mean SW values at both board sections were recorded from the boards fabricated with 7% resin loading.

In the case of the effect of kenaf particle content, it was discovered that greater kenaf particle loading contributed to greater SW value (Figure 10 and 11). Higher particle loading is believe to strengthen the boards as well as increases their densities, which these, helps the boards to hold the screws better. Screw withdrawal resistance is highly associated with the board density and the particle's geometry [31]. Overall, kenaf particleboard at 550 kg/m$^3$ has surpassed the minimum requirement of BS 5669 for SW at surface (480 N) and edge (360 N) for each sample group. Kenaf particleboards at 450 kg/m$^3$ were found to meet the standard requirement value when they were bonded with UF resin. It was unfortunate that none of the samples under 350 kg/m$^3$ have exceeded the BS 5669 requirements.

**Figure 9**: The screw withdrawal test

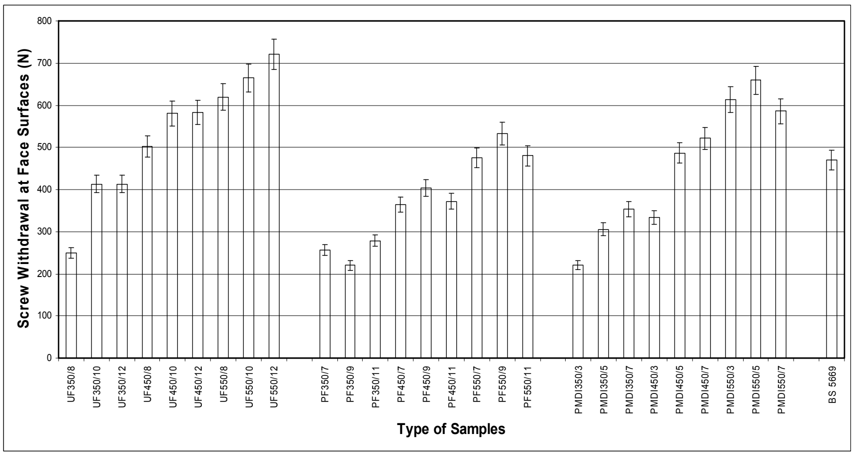


**Figure 10:** The screw withdrawal (face section) results of kenaf particleboards

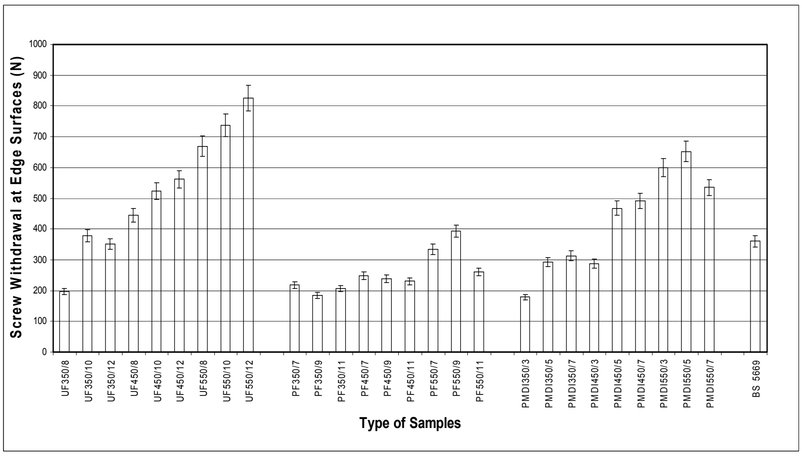


**Figure 11:** The screw withdrawal (edge section) results of kenaf particleboards

## 3.2 Physical Properties

Results of water absorption test are summarized in Figure 13. The results exhibited that the water absorption decreased with the increase of resin content. The situation found in each of the three different board types. This may due to the chemical components in the resin that is capable to cross-link with the hydroxyl groups of the kenaf fibres, 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 [34]. The 12% and 11% resin loading of UF and PF's board respectively and 7% resin loading for PMDI board have demonstrated the lowest water absorption values among the resin loading. The water absorption was also decreased as the kenaf particle loading increased and this happened to all board groups. This phenomenon may be explained by the theory of void over volume of board. The theory tells that greater existence of void which can mostly be found in low density particleboard than high density particleboard may provide spaces which encourage water absorption [32]. In low density board, the highly porous structure of the board allows water to penetrate into the board and increase water uptake resulting in high water absorption which at the same time, causes the board to swell and subsequently causes rise of thickness swelling (TS). In high density boards, the higher compaction ratio implies that more compressive deformation has been imparted onto the particles during hot pressing and the particles were under greater compressive set [31]. This situation reduces the formation of voids and reduces water absorption.

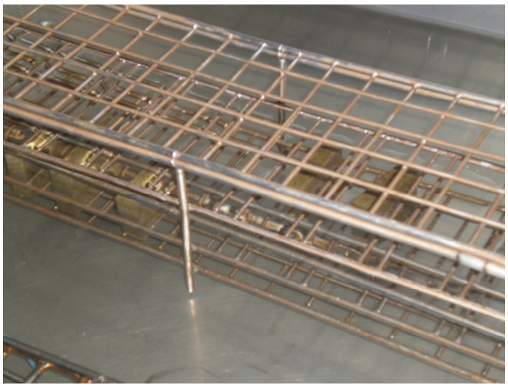

**Figure 12**: Water absorption and thickness swelling assessments

Results of thickness swelling are displayed in Figure 14.The thickness swelling was measured by calculating difference between the thicknesses of the sample before and after it is soaked in the water for 24 h. It has been found that the results of thickness swelling are similar to those under water absorption, since the thickness swelling is related to the water absorption. Thickness swelling values of UF, PF and MDI-bonded boards were not tally with the increase of resin loading. The TS values dropped when the resin loading rose.

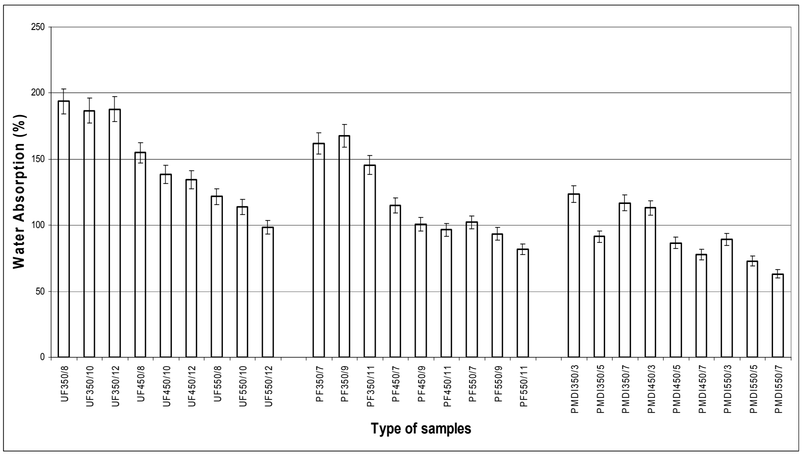


**Figure 13:** The water absorption results of kenaf particleboards

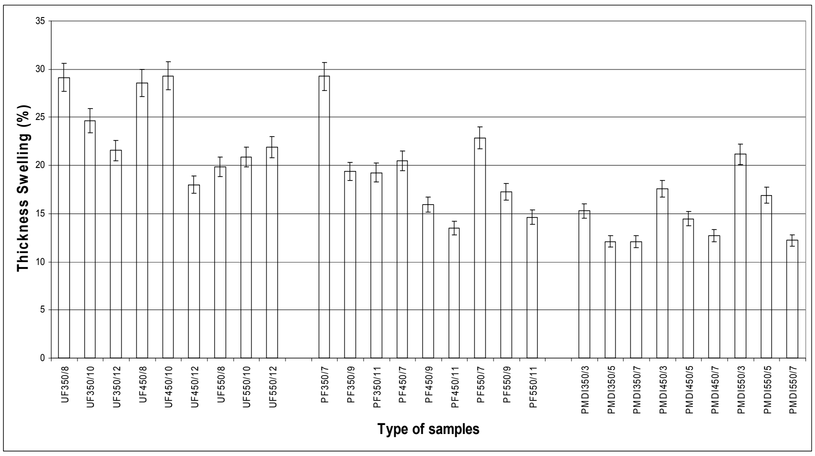


**Figure 14:** The thickness swelling results of kenaf particleboards

## 4. CONCLUSIONS

Board density, resin loading and particle loading were influential to the increment of physical and mechanical properties of the kenaf core particleboards. Particleboards manufactured with the density of 550 kg/m$^3$ were complied with the standard requirement values for bending strength, internal bond and screw withdrawal in accordance with British Standards (BS EN 312 and BS 5669). Insignificant results were recorded from other board densities under the similar tests conducted.

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