



## Effect of Wood Species, Resin level and Pressing time on the Quality of Particleboard

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Article history: Received: 10.03.2014

Accepted: 25.03.2014

### Abstract

Particleboards were prepared from three wood species, namely *Acacia nilotica* (sunt) *Boswellia papyrifera* (gafal) and *Ailanthus excelsa*, using three resin levels (9, 12 and 15 %) and three pressing times (6, 8 and 10 minutes). Prior to testing, the boards were conditioned for one week at a temperature of 25° C and relative humidity of 65%. The boards were evaluated by testing the following properties: modulus of rupture, modulus of elasticity, internal bond, water absorption and thickness swelling after two hours and twenty four hours soaking in water. Modulus of rupture (MOR) was highest for Sunt boards with 15% resin level, followed by ailanthus with no significant difference between them. It was lowest in case of Gafal boards and 9% resin level. Modulus of elasticity (MOE), on the other hand, was highest with *Ailanthus* boards and 15% resin level, and lowest with Gafal boards and 9% resin level. Internal bond (IB) was highest with Sunt boards followed by ailanthus without a significant difference between them and 15% resin level. Water absorption after 2 and 24 hours soaking in water (WA<sub>2</sub> and WA<sub>24</sub>) and thickness swelling (TS<sub>2</sub> and TS<sub>24</sub>) after 2 and 24 hours soaking, showed similar trends. The best boards were those made of Sunt and 15% resin levels, while the worse were those made of *Ailanthus* and 12% resin level.

**Key words:** Raw material – Adhesives - Mechanical properties - Physical properties

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### Introduction

The demand for composite wood products, such as particleboard, fiberboard, plywood, oriented strand board (OSB), hardboard, medium density fiberboard (MDF) and veneer has recently increased substantially throughout the world (Youngquist, 1999; Anonymous and Sellers, 2000). Particleboard consumption and use significantly increase each year. It represents about 57% of the total consumption of wood-based panels and continuously growing at 2-5% annually

(Drake 1997; Youngquist and Hamilton, 2000). Such rapid growth was due to the possibility of utilizing small-dimension wood including residues from other wood-using industries; availability of synthetic resins that facilitate mass production is another reason and above all, the suitability of the product for a variety of uses (Moslemi, 1977). Particleboards are among the most popular materials used in interior applications in floors, walls, ceiling panels, office partitions,

cabinets, furniture, counter and desktops. This extensive use of particleboards is mostly related to the economical advantage of the low cost wood raw material and simple processing technology (Wang and Sun, 2002). Now particleboard constitutes a cheap modern substitute for expensive products used for constructional purposes – plywood and sawn timber imports. The production of particleboard from agricultural residues and wood waste makes this industry economically and technologically attractive (Nasroun, 1986).

One of the main factors affecting the quality of particleboard is the type of raw material used. Other factors include the type of particles generated, the type of resin (binder), its amount and distribution among particles, mat moisture content and board density (Maloney, 1970; Nasroun, 2005). The particle geometry (size and shape) is a prime consideration affecting both the board properties and its manufacturing process. Indeed, the performance of the particleboard is the reflection of the particle characteristics. The mechanical strength of the boards i.e. bending, compression, tension parallel and perpendicular to the grain and screw and nail holding capacity are all important properties and are greatly affected by the particle geometry.

This research aimed at testing the suitability of three home-grown hardwood species for manufacturing particleboard and the manufacturing conditions for good quality boards.

## Materials and Methods

### Materials

The selected wood species for this research were *Acacia nilotica* (Sunt), *Ailanthus excelsa* and *Boswellia papyrifera* (Gafal), which were collected from the Blue Nile and Southern Kordofan States in the Sudan. These species were selected to represent

different densities, as density is the most important factor with regards to raw material. The resin type used in this experiment was Urea-formaldehyde (UF) 65% solid content, viscosity 400-800 millipascal/second. Ammonium Chloride ( $\text{NH}_4\text{Cl}$ ) 20% aqueous solution at 7% based on liquid resin was used as a hardener.

### Methodology

#### Preparation of particles

Logs from the three species were cut into discs of 20 cm. each. The discs were debarked, dried and then chipped using a medium size company chipper (VTT) at Otaniemi, Finland. Particles of 6 mm were produced through a 6 mm mesh for each species. The particles from the three species were then dried to moisture content of 5%. The dried particles were then used in the production of particleboards.

#### Manufacture of boards

The experimental boards were manufactured at the Laboratory of Wood Technology, Helsinki University of Technology (HUT), Otaniemi, Finland. The particles from each of the three species were weighed separately and their moisture content was reassessed based on the oven dry weight of wood. The chips were blended with 9% urea-formaldehyde (UF) 65% solid content and 7% ammonium chloride ( $\text{NH}_4\text{Cl}$ ) based on liquid resin was used as a hardener. Using a rotating blender fitted with a pneumatic spray gun, the mixture was blended for a total time of 2 minutes. No wax was added in the process. Mats of resin-coated particles were made and pressed in a computerized press at a temperature of 180°C using a pressure of 0.8 MPa to a target thickness of 12 mm. The target density for all boards was 0.75 gm/cm<sup>3</sup>

A second and a third set of panels were made likewise except for the resin level, which was changed to 12% and 15% respectively. Three pressing times were used 6, 8 and 10 minutes for each species/resin level combination. The

same blender and resin sprayer were used to prepare each mat. The blender was carefully cleaned between groups to avoid contamination. Prior to testing the boards were conditioned in a room for one week at a temperature of 25<sup>0</sup> C and a relative humidity of 65%.

### Evaluation of board quality

This was based on some mechanical and physical properties tested according to European standards for testing wood-based panels. Values for modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond strength (IB) were determined as the mechanical properties of the boards. Physical properties including thickness swelling (TS) and water absorption (WA), both after two hours and 24 hours soaking in water of the processed boards were also determined.

### Data Analysis

This was a factorial experiment with three factors run in a completely randomized design. The first factor was the wood species with three levels. The second factor was the resin amount represented by three levels; and the third factor was the pressing time again with three levels. Analysis of variance (ANOVA) was carried out to look for any significant differences between the various levels of each factor. ANOVA was followed by Duncan's Multiple Range Test to indicate the locations of the variations.

## Results and Discussion

### Variation of modulus of rupture (MOR) with the three factors

The results of analysis of variance (ANOVA) for MOR with the three factors: species, resin levels, pressing times and the interactions between them revealed significant differences in MOR between species ( $P < 0.0001$ ) and between resin levels ( $P = 0.0003$ ) but showed no significant differences between pressing times or interactions between these factors. This was supported by the results of the

Duncan's Multiple Range Tests (tables 1-3). Table 1 shows that Sunt had the highest value of MOR, followed by *Ailanthus* without a significant difference between them, (19.93 N/mm<sup>2</sup> and 19.68 N/mm<sup>2</sup> respectively). Gafal, however, had the lowest value (13.55 N/mm<sup>2</sup>) with significant difference from the other two species. The above results agree with earlier studies (Kimoto *et al.*, 1964). Which showed that MOR of panels is closely related to the species density and amount of resin used. Sunt has high density particles. Gafal, however, gave a low MOR value, which could be attributed to the inhibiting effect of other resinous materials present in the species. The high value for ailanthus could be attributed to the fact that low density woods could be compressed to high density stronger boards.

Table 2, on the other hand, shows the effect of resin level on MOR. It reveals that 15% resin level gave the highest value of MOR (19.29 N/mm<sup>2</sup>) followed by 12% resin level with no significant difference between them and lastly 9% level (16.04 N/mm<sup>2</sup>) which was significantly different from the other two levels.

Table 3 shows no significant differences in MOR with the pressing times used.

### Variation of modulus of elasticity (MOE) with the three factors

The results of the analysis of variance for MOE for the three factors and the interactions between them indicated significant differences in MOE between the species ( $P = 0.0001$ ) but showed no significant differences with both resin level and pressing time or the interactions between them. The results of the Duncan's Multiple Range Test (Tables 1-3) showed that *Ailanthus* had the highest MOE (3995.9 N/mm<sup>2</sup>) followed by Sunt (3625.0 N/mm<sup>2</sup>) but there was no significant difference between them. Boards from Gafal, however, gave the lowest MOE

value ( $1535.5 \text{ N/mm}^2$ ), which was significantly different from *Ailanthus* and *Sunt*. The high MOE obtained from *Ailanthus* species is explained by its low density, which confirmed increasing MOE with decreasing raw material density (Maloney, 1977; Haslett, 1986). However, the low MOE in *Gafal* could be as a result of some resinous materials. Particles from low density wood species are permeable to adhesives and compressible resulting in high inter-particle bonding and high board density.

The effect of the resin level on the MOE is shown in Table 2. The table reveals no significant differences in MOE values between the three resin levels but the highest value was obtained with 15% level ( $3162.9 \text{ N/mm}^2$ ) followed by 12% ( $3080.6 \text{ N/mm}^2$ ) and the lowest MOE value with 9% ( $2912 \text{ N/mm}^2$ ). Table 3 shows no significant differences in MOE with the different pressing times used.

#### **Variation of the internal bond (IB) with the three factors**

The results of the analysis of variance for the IB for the three factors and the interactions between them indicated significant difference in IB between resin levels ( $P=0.0009$ ) and to some extent between species ( $P=0.0347$ ). No significant differences were observed between, pressing times or their interactions. This result was also supported by the results of the Duncan's Multiple Range Test (Tables 1-3). Table 1 shows that the highest IB value was obtained from *Sunt* ( $0.4833\text{N}$ ) followed by *ailanthus* ( $0.4606\text{N}$ ) with no significant difference between them. *Gafal* showed the lowest IB value ( $0.4377\text{N}$ ), which was significantly different from the other two species. One would have expected *Ailanthus* and *Gafal* to have the highest IB because of the expected higher inter-particle bonds, but it seems that the high resin levels used in this investigation governed the results and masked the effect of inter-particle bonding.

Generally, this low value in IB is likely to be due to the improper coverage of resin on the particles surface as a result of uneven geometries.

Table 2, on the other hand, shows the effect of the resin level on the IB. It reveals that 15% resin content resulted in the highest IB value ( $0.5000 \text{ N}$ ) which was significantly different from levels 12% and 9% ( $0.4575 \text{ N}$  and  $0.4322 \text{ N}$  respectively). The value at 12% and 9% showed no significant difference between them. These results go in line with previous work (Kimoto *et al.*, 1964; Boquillon *et al.*, 2004). No significant differences existed in IB with pressing time (Table 3).

#### **Variation of water absorption after two hours soaking in water (WA<sub>2</sub>)**

The analysis of variance for the  $WA_2$  indicated significant differences in  $WA_2$  between species ( $P=0.0001$ ), between resin levels ( $P=0.0001$ ) and the interactions between these two factors ( $P=0.0001$ ) but showed no significant differences in pressing time. These results were confirmed by the results of the Duncan's Multiple Range Test (Tables 1-3).

Table 1 shows that the highest  $WA_2$  value was obtained from *ailanthus* (47.54%) followed by *Gafal* (41.60%) and lastly *Sunt* (39.23%) with significant differences between the three species. Table 2 shows that the highest  $WA_2$  value was obtained with 12% resin level (44.42%), followed by 9% level and lastly 15%, with significant differences between the three levels. Table 3 shows significant differences in  $WA_2$  between the 10-minutes pressing time, with the highest value, on one hand and the other two pressing times. Table 4 shows the effect of both the species and resin level on  $WA_2$ . The table reveals that the best combination was with *Sunt* at 15% resin level (38.69%) while the highest absorption level was with



*Ailanthus* with 12% resin level (53.43%). This is attributed to the differences in the permeability of the different species investigated.

#### **Variation of water absorption after twenty four hours soaking (WA<sub>24</sub>)**

The analysis of variance for the WA<sub>24</sub> for the three factors and their interactions showed significant differences in WA<sub>24</sub> values with species, resin levels and the interaction between these two factors (P=0.0001) but it does not show significant differences with the pressing time and its interactions with the other factors. This result was also supported by the results of the Duncan's Multiple Range Test (Tables 1-3). Table 1 shows that *ailanthus* had the highest WA<sub>24</sub> value, followed by Gafal and then Sunt (49.75, 43.62 and 40.36% respectively) with significant differences between the three species. This is understandable since low density woods are usually more permeable to liquids. Table 2, on the other hand, gives the effect of the resin level on the WA<sub>24</sub>. It indicated that the 12% resin level gave the highest WA<sub>24</sub> value, followed by 9% resin level and lastly 15% resin level (46.07, 44.68 and 42.99% respectively) with significant differences between them.

The results also showed no significant differences in WA<sub>24</sub> values with the three pressing times used (Table 3). Table 5 shows that the least absorption level was also obtained with Sunt at 15% resin level (39.69%), while the highest was with *Ailanthus* at 12% resin level (55.56%).

#### **Variation of thickness swelling after two hours soaking in water (TS<sub>2</sub>)**

The results of the analysis of variance for TS<sub>2</sub> for the three factors and the interactions between them showed significant differences in the values of the TS<sub>2</sub> between species, between resin levels and between pressing times (P=0.0001). The results also indicated a

significant difference in the interaction of the species with the resin level (P=0.0001). The results of the Duncan's Multiple Range Test (Tables 1-3) revealed that *Ailanthus* had the highest TS<sub>2</sub> value followed by Gafal and lastly Sunt (20.34, 17.93 and 16.02% respectively) which were significantly different from each other. Table 2 indicates that 12% resin level produced boards with the highest TS<sub>2</sub> values (18.91%) which was significantly different from the other two levels 9% (17.89%) and 15% (17.54%) which were not significantly different from each other. In table 3 significant differences in the values of the TS<sub>2</sub> with the three pressing times were found. The highest value of TS<sub>2</sub> was obtained with 10 minutes pressing time (18.76%) followed by 8 minutes pressing time (18.03%) then 6 minutes pressing time (17.55%). Table 6 shows that TS<sub>2</sub> followed the same trend as WA<sub>2</sub> and WA<sub>24</sub>, that is, the least TS<sub>2</sub> was obtained with Sunt at 15% resin level (15.80%), while the highest was with *ailanthus* at 12% resin level (22.80%).

#### **Variation of thickness swelling after twenty four hours soaking in water (TS<sub>24</sub>)**

The results of the analysis of variance for TS<sub>24</sub> for the three factors and their interactions showed significant differences in TS<sub>24</sub> values between the species, the resin levels, the pressing times and the interaction between the species and the resin level (P=0.0001). This result was further confirmed by the results of the Duncans Multiple Range Test (Tables 1-3). Table 1 indicates the effect of species on TS<sub>24</sub>. It shows a higher TS<sub>24</sub> value with *Ailanthus* species (20.78%), followed by Gafal (18.04%) and then Sunt (16.26%) which were significantly different from each other. Table 2 shows the effect of the resin level on the TS<sub>24</sub>. It clearly shows that 12% resin level resulted in the highest TS<sub>24</sub> value (19.15%) which was significantly different from the values obtained from 9% (18.07% and 15% (17.85%). But there was

no significant difference in  $TS_{24}$  between the resin levels 9% and 15%. Variation in the effect of the pressing time on the  $TS_{24}$  is given in Table 3. The table shows significant differences in the values of  $TS_{24}$  with the pressing times applied. The 6 minutes pressing time resulted in the highest  $TS_{24}$  value (18.98%) followed by 8 minutes pressing time (18.29%) and lastly 10 minutes pressing time (17.80%) which were significantly different from each other. Table 7 shows the variation of  $TS_{24}$  with species and resin levels. It showed the same trend as with  $WA_2$ ,  $WA_{24}$  and  $TS_2$  in that the highest  $TS_{24}$  value was obtained with *Ailanthus* at 12% resin level while the lowest value was obtained with *Sunt* at 15% resin level.

All the properties obtained from this investigation were better than the requirements for load bearing regular particleboard stated in the International Standard – ISO 16893-2: 2010 (E). This was due to the extremely high resin levels used in

this investigation, which was recommended in Finland where the first author made the boards.

### Conclusion

- 1- All the strength properties were highest with *sunt* and *ailanthus* using 15 % resin level with no significant difference between them.
- 2- Water absorption and thickness swelling showed similar trends- they were highest with *ailanthus* using 12 % resin level.
- 3- *Sunt* boards using 15 % resin level were the most resistant to water absorption and thickness swelling.
- 4- Resin levels used were too high for this kind of product.

### Recommendation

It is recommended to use lower resin levels in future trials (10, 8 and 6 % ) and to introduce pressure level as a factor.

**Table 1: Variation of particleboard mechanical properties with species**

Species	MOR N/mm <sup>2</sup>	MOE N/mm <sup>2</sup>	IB N
<i>Sunt</i>	19.93 A	3625.0 A	0.4833 A
<i>Gafal</i>	13.55 B	1535.5 B	0.4377 B
<i>Ailanthus</i>	19.68 A	3995.9 A	0.4686 A

Means with the same letters are not significantly different

\* MOR = modulus of rupture, MOE = modulus of elasticity, IB = internal bond,  $WA_2$  = water absorption after 2 hours soaking,  $WA_{24}$  = water absorption after 24 hours soaking,  $TS_2$  and  $TS_{24}$  = thickness swelling after 2 and 24 hours soaking, respectively. This applies to l tables 1-3.

**Table 2: Variation of particleboard mechanical properties with resin levels**

Resin levels (%)	MOR N/mm <sup>2</sup>	MOE N/mm <sup>2</sup>	IB N
9	16.04 B	2912.9 A	0.4332 B
12	17.83 A	3080.6 A	0.4575 B
15	19.29 A	3162.9 A	0.5000 A

Means with the same letters are not significantly different

Abbreviations are the same as in table 1

**Table 3: Variation of particleboard mechanical properties with pressing times**

Pressing times	MOR* N/cm <sup>2</sup>	MOE N/cm <sup>2</sup>	IB N
6	17.23 A	3127.7 A	0.4482 A
8	17.84 A	3083.1 A	0.4838 A
10	18.08 A	2945.6 A	0.4577 A

Means with the same letters are not significantly different at P = 0.05.

**Table 4: Variation of WA<sub>2</sub> with species and resin level**

Species	Water absorption (2 hrs) for resin levels (%)		
	9	12	15
Sunt	39.99 aB	39.06 bB	38.69 bC
Gafal	44.19 aA	40.76 bB	39.85 cB
Ailanthus	44.44 bA	53.43 aA	44.76 bA

Means with the same capital letters down the columns are not significantly different

Means with the same small letters along the rows are not significantly different at P= 0.05.

**Table 5: Variation of WA<sub>24</sub> with species and resin level**

Species	Water absorption (24 hrs) for resin levels (%)		
	9	12	15
Sunt	41.17 aB	40.25 bB	39.67 cC
Gafal	46.25 aA	42.40 bB	42.20 bB
Ailanthus	46.61 bA	55.56 aA	47.09 bA

Means with the same capital letters down the columns are not significantly different

Means with the same small letters along the rows are not significantly different at P= 0.05.

**Table 6: Variation of TS<sub>2</sub> with species and resin level**

Species	Thickness swelling ( 2hrs ) for resin level (%)		
	9	12	15
Sunt	16.33 aB	16.07 aBC	15.80 bC
Gafal	18.82 aA	17.87 bB	17.10 cB
Ailanthus	18.51 bA	22.80 aA	19.72 bA

Means with the same capital letters down the columns are not significantly different

Means with the same small letters along the rows are not significantly different at P=0.05

**Table 7: Variation of TS<sub>24</sub> with species and resin level**

Species	Thickness swelling (24hrs) for resin level (%)		
	9	12	15
Sunt	16.47 aB	16.32 aC	15.98 bC
Gafal	18.99 aA	18.00 bB	17.04 cB
Ailanthus	18.75 cA	23.15 aA	20.44 bA

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## تأثير نوع الخشب ونسبة المادة اللاصقة ومدة الضغط على نوعية ألواح الخشب الحبيبي

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### المستخلص

تم إعداد ألواح الخشب الحبيبي من ثلاثة أنواع من الأخشاب شملت: السنط والقفل والإيلانيس وذلك باستخدام ثلاثة مستويات من المادة اللاصقة يوريا فورمالدهيد- 9 و 12 و 15%. وأعدت الألواح تحت ضغط ودرجات حرارة عالية. واختلفت مدة الضغط بين 6 و 8 و 10 دقائق. بعد ذلك تركت الألواح لتتواءم مع ظروف المعمل تحت درجة حرارة 25 درجة مئوية ورطوبة نسبية 65%. ومن ثم بدأ تقييم نوعية الألواح المنتجة بإجراء الاختبارات اللازمة لتحديد الخصائص التالية: قوة الإنحناء ومعامل المرونة وقوة ترابط الحبيبات (قوة الشد العمودية على سطح اللوح) بالإضافة إلى نسبة إمتصاص الماء ونسبة إنتفاخ سمك الألواح بعد نقعها في الماء لمدة ساعتين وأربعة وعشرين ساعة. وأظهرت النتائج أن قوة إنحناء الألواح كانت أعلاها مع خشب السنط المخلوط مع 15% مادة لاصقة (19.93) يليه الإيلانيس (19.68) بدون فرق معنوي بينهما. أما معامل المرونة فقد بلغ أعلاه مع الإيلانيس المخلوط مع 15% مادة لاصقة (3996 N/cm<sup>2</sup>) وأدناه مع القفل المخلوط مع 9% مادة لاصقة (1536 N/cm<sup>2</sup>). وبلغت قوة الترابط الداخلي (Internal bond) أعلاها مع السنط المخلوط مع 15% مادة لاصقة (0.48) يليه الإيلانيس مع نفس نسبة المادة اللاصقة (0.47 N) وبدون فرق معنوي بينهما. وظهر من نسبة إمتصاص الماء ونسبة إنتفاخ السمك بعد نقع الألواح في الماء لمدة ساعتين و 24 ساعة نفس التوجهات حيث كانت ألواح السنط المخلوط مع 15% مادة لاصقة أكثر الألواح مقاومة لامتناس الماء وانتفاخ السمك وأقلها مقاومة ألواح الإيلانيس المخلوط مع 12% مادة لاصقة.