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# MACHINING PROPERTIES OF NATURAL REGENERATION AND PLANTED *ACACIA MANGIUM* × *A. AURICULIFORMIS* HYBRID

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Machining properties of *Acacia mangium* × *A. auriculiformis* hybrid wood was evaluated in this study. Sawing, planing and boring tests were conducted to assess the machining properties of *Acacia* hybrid wood obtained from two different study sites, namely, mature natural regeneration and plantation-grown areas. For each study site, stressed and non-stressed trees were selected and felled at 15 cm above ground. Samples with dimensions of 20 mm × 100 mm × 900 mm were then prepared from three different height levels (top, middle, bottom) of the felled logs prior to machining test. The results showed that non-stressed wood generally had better sawing, planing and boring characteristics than stressed wood. In terms of height level, there was no significant difference between height levels and machining properties of the wood samples.

Keywords: Sawing, planing, boring, stressed trees, non-stressed trees

## INTRODUCTION

The first hybrid of *Acacia mangium* and *A. auriculiformis* was discovered in 1971 near Ulu Kukut Plantation in north-western Sabah, Malaysia (Rufelds 1987). The hybrids were natural regeneration and were progenies of the two *Acacia* species that had been planted in close proximity. Subsequently, seedlings from the seeds collected from the area and planted elsewhere gave rise to hybrid of *A. mangium* and *A. auriculiformis* in other localities. Now, *A. mangium* × *A. auriculiformis* has become an increasingly significant tree variant in plantation forestry (Jusoh et al. 2014, Tanaka et al. 2015, Bon & Harwood 2016). This is because *Acacia* hybrid exhibits better properties in comparison with its predecessors. It is less susceptible to heart rot disease compared with *A. mangium* (Ito & Nanis 1997). It is also denser and inherits the better stem straightness of *A. mangium* as well as self-pruning ability and better stem circularity of *A. auriculiformis* (Mohd Hamami & Semsolbahri 2003).

Dependence on plantation wood is increasing because, although selective logging is being practised, harvest cycle of 30 years was insufficient for logged forests to recover to the status of unlogged forest (Do et al. 2016). Therefore, wood supply deficiency is anticipated in the near future. Wood is an important industrial raw material and one of the few renewable natural resources. Therefore, in order to determine its suitability and potential usage, a wide knowledge of wood growth and properties as well as its characteristics are important matters to be considered. Nevertheless, little information regarding the properties of *Acacia* hybrid is currently known, especially its machining properties (Rokeya et al. 2010, Jusoh et al. 2014). Machining properties are very important to determine the surface quality of solid wood and wood products that will affect the finishing or adhesive strength properties (Sofuoglu 2017). Wood with good machining properties could be used in industrial applications of high value-added products (Ruiz Aquino et al. 2017). In this study, machining properties of *A. mangium* × *A. auriculiformis* hybrid such as sawing, planing and boring were assessed and compared between stressed and non-stressed samples as well as height levels (top, middle and bottom).

## MATERIALS AND METHODS

### Study area, tree sampling and preparation of samples

*Acacia* hybrid samples used in this study were obtained from the Sabah Forestry Development Authority Forest Reserve located at Ulu Kukut, Kota Belud District, Sabah (6° 40' N, 116° 50' E). Two specific sites were selected for the collection of tree samples. The first area was an area with mature natural regeneration hybrid and the second was an area with plantation-grown hybrid with a spacing of 3.0 m × 3.0 m. Stressed and non-stressed tree samples were then selected from each study site. Stressed tree samples of mature natural regeneration were collected from areas near gaps or border, where trees that grew in these areas tended to incline to the side or towards the direction where no tree existed, while non-stressed samples were obtained from normal stand. For plantation trees, stressed samples were collected from trees grown on the slope of about 30% while non-stressed samples were taken from the flat area. A total of 20 trees were felled at 15 cm above ground level (5 stressed and 5 non-stressed for each study site). Full logs were live sawn and cut into boards with dimensions of 35 mm thickness and 2 m length. Dimensions of each sample for sawing, planing and boring tests were 20 mm × 100 mm × 900 mm. Samples were taken from three different heights of the tree, namely top, middle and bottom portions. Sawing patterns of both stressed and non-stressed wood are illustrated in Figure 1. The detailed number of samples taken is shown in Table 1.

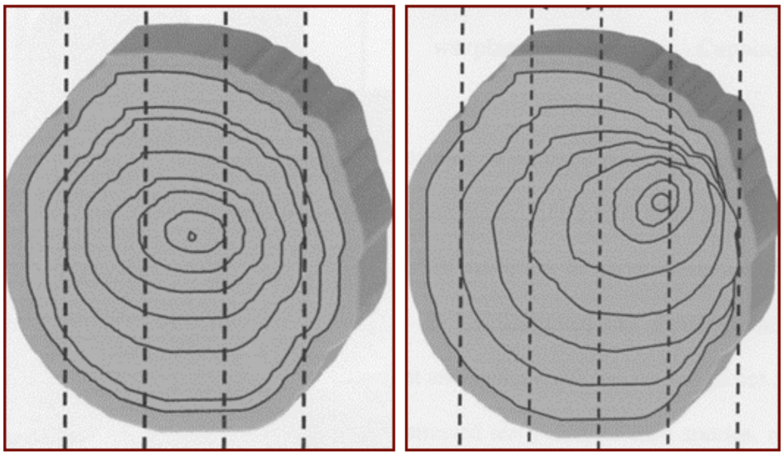

**Figure 1** Live sawing process of non-stressed and stressed wood

**Table 1** Sampling numbers for machining properties test

| Generation category | Growth category | Height level | Sawing (N) | Planing (N) | Boring (N) |
|---|---|---|---|---|---|
| Mature natural regeneration | Stressed | Top | 5 | 3 | 28 |
| | | Middle | 15 | 4 | 32 |
| | | Bottom | 24 | 4 | 64 |
| | Non-Stressed | Top | 38 | 10 | 8 |
| | | Middle | 33 | 10 | 12 |
| | | Bottom | 60 | 14 | 19 |
| Plantation grown | Stressed | Top | 12 | 2 | 8 |
| | | Middle | 9 | 2 | 20 |
| | | Bottom | 14 | 2 | 8 |
| | Non-Stressed | Top | 9 | 2 | 12 |
| | | Middle | 16 | 4 | 20 |
| | | Bottom | 16 | 10 | 8 |

## Evaluation of machining properties

Sawing, planing and boring tests of the samples were conducted in accordance to ASTM D 1666-11 (ASTM 2011). Testing was conducted at the Wood Industry Skills Development Centre, Olak Lempit, Banting, Selangor. Machining tests were conducted to determine the characteristics of different wood under a variety of machine operations. The quality of finished surface was the basis for evaluation of the machining properties. Rate of dulling of cutting tools and power consumed in cutting are also important considerations but are beyond the scope of these methods.

Visual examination for each testing samples was made on the basis of defect-free surface and graded as shown in Table 2. For the sawing test, the cuts of wood were graded visually based on roughness of the edge surface. Planing was evaluated based on the occurrence of raised grain, fuzzy grain, torn grain and chip mark, in which the less, the better the planing properties. Raised grain refers to fibre bundles which tend to spring back into elevated position after machining because of the compression rather than cutting action. Torn grains are torn out bundles leaving depressions on the machined surface. Fuzzy grains are torn and bent fibre bundle, resulting in a woolly surface after machining. Boring properties were evaluated according to crushing, tearing, fuzziness and general smoothness of the holes created. From visual examination, the samples were grouped into two categories, namely, grades 1 and 2 which were considered acceptable quality while grades 3 to 5, low quality.

Samples of planks from both sites were cross-cut using a circular saw (300 mm diameter × 3.2 mm cutting width × 30 mm bore size and number of teeth = 60). The cutting direction was across the grain at 4000 rpm. The percentage of edge surface quality for each sample from the stressed and non-stressed wood of each category was determined and calculated based on the five visual examinations grades (Table 2).

A thickness planer were used for the planing test. This machine had a cutter block attached with 4 wing blades at 27° cutting angle and rotates at 4500 rpm. Direction of planing was along the grain with depth of cut between 0.5 and 3 mm and feeding speed was about 12 m $min^{-1}$. After planing, samples were examined and the percentage of the defect-free surface was determined and calculated based on visual examinations (Table 2). The quality criteria used were raised grain, torn grain and fuzzy grain. For the present study, observation was made by determining the acceptable and low qualities of the sample surface taken from two different growth categories and three different height levels of the tree.

The borer used in this boring testing was a single-spindle electric machine with a rotation speed of 1430 rpm and hand feed of about 0.6 m $min^{-1}$. The drill bit used was 16-mm diameter of the single, solid centre brand-point type. Boring properties of different wood were calculated based on the examination of fuzziness of the holes and general smoothness of cut.

## RESULTS AND DISCUSSION

The board surface quality after the sawing process is illustrated in Figure 2. Stressed wood samples produced rougher edge surface than the non-stressed wood planks. Higher percentage of low quality surface produced by sawing cut of 59.1 and 65.7% can be seen in stressed mature natural regeneration and plantation-grown samples respectively (Table 3) compared with non-stressed mature natural regeneration (48.9%)

**Table 2** Grading categories for machining properties

| Grade | Description |
|---|---|
| 1 | Excellent—more than 80% defect free surface |
| 2 | Good—65 to 79% defect free surface |
| 3 | Fair—45 to 64% defect free surface |
| 4 | Poor—35 to 44% defect free surface |
| 5 | Very poor—below than 34% defect free surface |


**Figure 2** Surface quality of stressed and non-stressed wood after sawing test; clean surface cut signifies acceptable quality (left) while unclean surface cut signifies low quality (right)

**Table 3** Surface quality of sawing test between height levels of *Acacia* hybrid wood

| Generation category | Growth category | Height level | N | Surface quality (%) | | | | p value |
|---|---|---|---|---|---|---|---|---|
| | | | | Grades 1 to 2 (Acceptable quality) | Average[1] | Grades 3 to 5 (Low quality) | Average[1] | |
| Mature natural regeneration | Stressed | Top | 5 | 40.0 | 40.9 | 60.0 | 59.1 | 0.741 ns |
| | | Middle | 15 | 33.3 | | 66.7 | | |
| | | Bottom | 24 | 45.8 | | 54.7 | | |
| | Non-stressed | Top | 38 | 47.7 | 51.1 | 52.6 | 48.9 | 0.252 ns |
| | | Middle | 33 | 63.6 | | 36.4 | | |
| | | Bottom | 60 | 46.7 | | 53.3 | | |
| Plantation grown | Stressed | Top | 12 | 41.7 | 34.3 | 58.3 | 65.7 | 0.643 ns |
| | | Middle | 9 | 22.2 | | 77.8 | | |
| | | Bottom | 14 | 35.7 | | 64.3 | | |
| | Non-stressed | Top | 9 | 55.6 | 63.4 | 44.5 | 36.6 | 0.802 ns |
| | | Middle | 16 | 62.5 | | 37.5 | | |
| | | Bottom | 16 | 68.8 | | 31.3 | | |

ns = not significant at $p \leq 0.05$; [1]= average value of top, middle and bottom levels for each generation and growth category and plantation-grown (36.6%) samples. The percentage of acceptable surface cut was highest in the non-stressed plantation-grown samples (63.4%). This indicated that non-stressed wood produced smoother surface cut than stressed wood. This finding was similar to Tan (2002) who found that sawing process of stressed wood produced rougher surface than non-stressed wood. Stressed and non-stressed wood tend to have different wood qualities as a result of different fibre length and wall thickness caused by different growth conditions (Naji et al. 2014).

Board surface qualities of sawing samples taken from different height levels are tabulated in Table 3. For mature *Acacia* hybrid from natural regeneration, both stressed and non-stressed wood had less samples graded as acceptable quality (grades 1 and 2). The highest percentage of acceptable quality samples (63.6%) was found in the middle part of non-stressed mature natural regeneration *Acacia* hybrid. All levels (top, middle and bottom) of non-stressed plantation-grown trees showed better surface quality with the best (68.8%) sawing characteristic observed in samples from the bottom part. However, Pearson chi-square analysis showed that there was no significant difference between surface quality grade and height level of trees (Table 3).

Surface quality of *Acacia* hybrid after planing process is displayed in Figure 3 while the results of surface quality based on generation and growth categories are summarised in Table 4. *Acacia*


**Figure 3** Surface quality of stressed and non-stressed wood after planing test

**Table 4** Surface quality of planing test between height levesl of *Acacia* hybrid wood

| Generation category | Growth category | Height level | N | Surface quality (%) | | | | p value |
|---|---|---|---|---|---|---|---|---|
| | | | | Grades 1 to 2 (Acceptable quality) | Average[1] | Grades 3 to 5 (Low quality) | Average[1] | |
| Mature natural regeneration | Stressed | Top | 3 | 0 | 9.1 | 100 | 90.9 | 0.382 ns |
| | | Middle | 4 | 0 | | 100 | | |
| | | Bottom | 4 | 25.0 | | 75.0 | | |
| | Non-stressed | Top | 10 | 0 | 14.7 | 100 | 85.3 | 0.132 ns |
| | | Middle | 10 | 10.0 | | 90.0 | | |
| | | Bottom | 14 | 28.6 | | 71.4 | | |
| Plantation grown | Stressed | Top | 2 | 0 | 0 | 100 | 100 | NA |
| | | Middle | 2 | 0 | | 100 | | |
| | | Bottom | 2 | 0 | | 100 | | |
| | Non-stressed | Top | 2 | 0 | 6.3 | 100 | 93.8 | 0.726 ns |
| | | Middle | 4 | 0 | | 100 | | |
| | | Bottom | 10 | 10.0 | | 90.0 | | |

ns = not significant at $p \leq 0.05$; NA = not available; [1]= average value of top, middle and bottom levels for each generation and growth category hybrid had low surface quality. Both stressed and non-stressed samples for all three height levels showed very low percentages of samples graded as acceptable quality. Stressed and non-stressed natural regeneration samples had only 9.1 and 14.7% samples of acceptable quality respectively. None of the stressed plantation-grown samples was classified as acceptable. Plantation-grown Scots pine in Finland exhibited inferior external quality in comparison with that of natural regenerated trees (Huuskonen et al. 2008). Naturally regenerated stands possessed superior quality because of their relatively stable root system compared with the plantation-grown trees (Agestam et. al 1998). Naturally regenerated trees usually grow in conditions with higher heterogeneity where other shelter tree species co-exist and result in severer competition among them. Timber quality is improved under these competitive conditions. The bottom part of all *Acacia* hybrid samples exhibited slightly better surface quality wood after planing, but not significant, in comparison with the other parts of the trees (Table 4).

Generally, non-stressed wood produced more clean holes than stressed wood (Figure 4). Tan (2002) reported that the inside surface of bored holes was cleaner in non-stressed wood compared with stressed wood. The boring characteristics of *Acacia* hybrid in this study was found comparable with that of rubberwood which is classified as grades 1 to 2 (Bakar et al. 2017). Results in Table 5 indicated that there were more low quality hole compared with acceptable quality hole, the highest being in stressed plantation-grown samples (75%). For mature natural regeneration, all samples showed better quality than plantation-grown

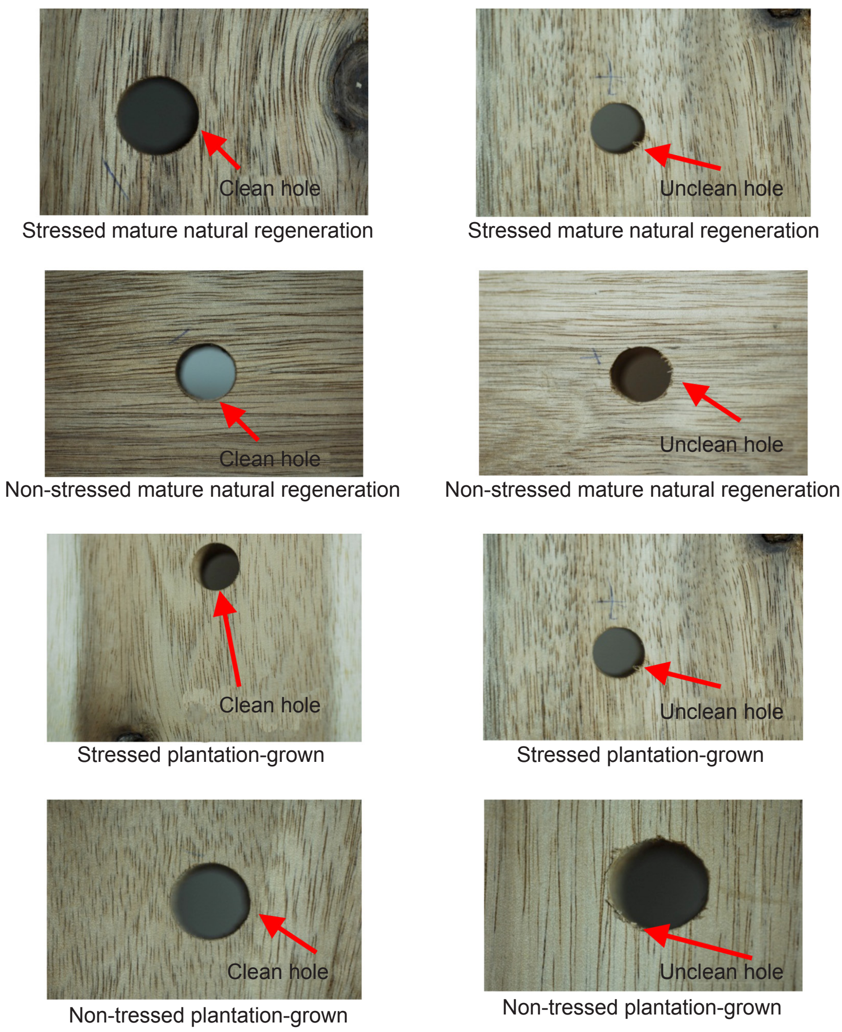


**Figure 4** Surface quality of stressed and non-stressed wood after boring test; clean hole signifies acceptable quality while unclean hole, low quality

 

**Table 5** Surface quality of boring test between height levels of *Acacia* hybrid wood

| Generation category | Growth category | Height level | N | Surface quality (%) | | | | p value |
|---|---|---|---|---|---|---|---|---|
| | | | | Grades 1 to 2 (Acceptable quality) | Average[1] | Grades 3 to 5 (Low quality) | Average[1] | |
| Mature natural regeneration | Stressed | Top | 28 | 57.1 | 60.5 | 42.9 | 39.5 | 0.246 ns |
| | | Middle | 32 | 50.0 | | 50.0 | | |
| | | Bottom | 64 | 67.2 | | 32.8 | | |
| | Non-stressed | Top | 8 | 87.5 | 66.7 | 12.5 | 33.3 | 0.213 ns |
| | | Middle | 12 | 50.0 | | 50.0 | | |
| | | Bottom | 19 | 68.4 | | 31.6 | | |
| Plantation grown | Stressed | Top | 8 | 25.0 | 25.0 | 75.0 | 75.0 | 0.627 ns |
| | | Middle | 20 | 20.0 | | 80.0 | | |
| | | Bottom | 8 | 37.5 | | 62.5 | | |
| | Non-stressed | Top | 12 | 75.0 | 48.5 | 25.0 | 51.5 | 0.009* |
| | | Middle | 20 | 20.0 | | 80.0 | | |
| | | Bottom | 8 | 37.5 | | 62.5 | | |

ns = not significant at $p \leq 0.05$, * = significant at $p \leq 0.05$; [1]= average value of top, middle and bottom levels for each generation and growth category

samples. Planted trees have higher growth rate compared with naturally regenerated trees (Ackzell 1993). Faster growth rate resulted in increment of juvenile core area which subsequently lowers wood density (Macdonald et al. 2010). The best boring characteristic was found in the samples with higher density, therefore, wood extracted from natural regenerated stands displayed superior boring properties than planted trees (Addae-Mensah & Ayarkwa 1993). As for height level categories, the result in Table 5 showed that better boring quality was found in the bottom parts of the logs for both stressed mature natural regeneration and plantation-grown samples. However, no significant difference in boring quality was observed between the samples from all three height levels probably due to the fact that trees growing in stressed condition had more uniform distribution of tracheid wall thickness (Zhu et al. 2007). Percentage of acceptable quality holes for both non-stressed mature natural regeneration and plantation-grown samples were higher at the top part of the tree. This could be attributed to the increasing specific gravity towards the top part of the trees under normal growth condition. Wood with higher specific gravity produces higher percentage of good and excellent holes (Addae-Mensah & Ayarkwa 1993).

## CONCLUSIONS

In the sawing test, non-stressed wood produced smoother surface cut than stressed wood. However, no significant difference in sawing properties was found between the height levels where the samples were taken. Overall, planing characteristic of *Acacia* hybrid were very poor where only a small number of samples with acceptable quality were obtained. Similar to sawing properties, stressed wood generally produced rougher surface than non-stressed wood during planing process and the height levels did not significantly affect the planing properties. In the boring evaluation, the non-stressed wood produced more cleaner holes than the stressed wood. Significantly better boring properties was observed in the top part of non-stressed plantation-grown wood probably due to its higher specific gravity. Therefore, it can be concluded that the mature natural regeneration and plantation-grown non-stressed wood have better machining properties than that of stressed wood.

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