PROPERTIES OF BENT RUBBERWOOD IN DIFFERENT STORING CONDITIONS

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ABSTRACT. *Bending is an important element in producing good quality furniture. Bentwood has the tendency to springback to its original position after undergoing the bending process. Assessing the springback and moisture uptake after the wood has been bended into the desired form is critical in determining as to whether a particular wood is suitable for bending purposes. Rubberwood was used in this study for making bending component in furniture. After undergoing the bending process, the bentwood were stored in workshop and air-conditioned rooms for assessing their springback properties. Factors such as the wood thickness and radius of curvature were studied as they influence springback. The wood were first plasticised by soaking them in hot water at 70°C for 1 hour and steamed in a steaming chamber at 105°C for 25 mins. Then the wood were placed inside a stainless steel strap and pressed in a moulded hot press at three radius of curvatures (600 mm, 900 mm and 1200 mm) and four types of thickness (15 mm, 20 mm, 25 mm and 30 mm). The bentwood were then further heated for 25 mins to fixation. The results showed the springback and the moisture uptake were high in the workshop condition. Storage condition and thickness had significant effect on the moisture uptake and springback but not the radius. Air-conditioned room should be used as storage for bentwood in order to minimise the moisture uptake and springback. The thicker bentwood had the lowest springback and moisture uptake. There was a strong linear relationship between the springback and the moisture uptake.*

KEY WORDS. Steam bending, bentwood, springback, moisture uptake, rubberwood

INTRODUCTION

Bentwood normally used in furniture such as rocking chairs, cafe chairs, that are made by steaming wood, bending it, and letting it harden into curved shapes and patterns is also popular and often used in the production of musical instruments, toys, barrels and sporting goods (Makinaga, *et al*, 1997). The process was developed by Michael Thonet, a German who received a patent in 1856. Today the process of wood bending is still practice by furniture manufacturers in many part of the world. It is still in widespread use for making casual and informal furniture of all types, particularly seating and table forms. It is also a popular technique in the worldwide production of furniture with frames made of heavy cane.

Bending of wood can be achieved once the minimum radius of curvature of the wood has been determined. This radius of curvature is required as it determine the minimum radius whereby the wood can be bends without damaging the wood structure or properties. The minimum radius of curvature varies according to wood species and their sizes.

A reasonable percentage of faultless bends can be obtained for a given thickness of solid material, both when that material is efficiently supported by means of a metal strap or when unsupported (Ser, *et al*, 1987). Most tropical hardwoods have either moderate or poor bending qualities. Tropical timbers were often found to be generally unsuitable for solid wood bending work. This is mainly due the presence of fungi, pinholes that are caused by insect attack, natural compression failures or brittle heart (Anon, 1969). However, wood of six commercially important Indian timber species gave satisfactory bends radius of 100 - 175 mm in 13 and 25 mm thick strips when plasticised with ammonia at 5 kg/cm^2. The woods were *Acrocarpus fraxinifolius, Grevillea robusta, hevea brasiliensis, Morus alba, Populus deltoides and Tectona grandis* (Pandey, 1995). The bending ratings of Chinese guger-tree were influenced by the thickness of the specimens and its curvature. Percentage of acceptable bentwood increased with decreasing thickness and increasing radius. Statistical analysis also indicated that the final curvatures of the bentwood correlated with the degrees of instantaneous recovery (Chin, 1988). According to Zhang (1987) changes in radius of curvature depended only on changes in moisture content.

During the bending process, tensile and compression, strains are induced to the bentwood. The bentwood is usually strained beyond its elastic limit so that some permanent deformation of the fiber occurs. For this reason, a bend that is allowed to move seldom returns completely to its former shape. When, however, the induced strains are below the elastic limit, removal of all restraint results in almost complete removal of the strain in the fibres and hence the piece will return very nearly to its shape (Steven & Turner, 1970). Similarly, the intention to release the tension back to the natural matrix of the normal wood is severed if the bentwood is exposed to the high relative humidity condition. Therefore, to overcome this matter the bentwood must be dried to appropriate moisture content and placed in suitable condition. In this study, the springback and moisture uptakes of rubberwood were analysed. Parameters such as the wood thickness, radius od curvature and condition related to the effect of springback was studied to evaluate the critical factors for the springback. Rubberwood was chosen as it is an important wood species in Malaysia and is used extensively for producing furniture.

MATERIALS AND METHOD

Rubberwood (*Hevea Brasiliensis*) of age of twenty five years were felled and the billets were sawn and later kiln dried to 12% moisture content. All wood samples were taken at dbh and having an average density of 680 kg/m^3 and specific gravity of 0.68. A total of 120 pieces samples of 446 x 50 mm were produced in four different thickness namely 15 mm, 20 mm, 25 mm and 30 mm. Samples were coded and marked at the centre of each board for easy identification. They were later soaked in hot water of 70ºC for about 60 min. Prior to this process an oxalic acid 0.05 %w/w was mixed into the hot water in order to soften and bleach the samples. Then the specimens were steamed in a steaming chamber for 25 min at 100ºC with pressure of 0.5 kg/cm^2 for further softening treatment. The specimens were then removed immediately and placed to a stainless steel strap with double end stopper. The strap was purposely set on the tension side. This is to prevent the specimens from being over stretched. Subsequently, the samples were immediately placed in a hot press of 100ºC for about at 25 min. The hot press moulds have three radius of curvature namely 600 mm, 900 mm and 1200 mm. The female and male moulds were pressed in a hydraulic press with pressure of 4 kg/cm^2. The samples were fixed inside the mould of the hot press for 30 minutes for cooling before taken out. The tests on samples were made in accordance to the procedure developed by the Wood Research Institute Kyoto University (Norimoto, 1993).

The springback was determined by placing the bentwood on a piece of paper and tracing the shape. Then, the samples were weight and conditioned in a conditioning chamber at temperature 25°C and relative humidity 65% for 10 days. Samples were exposed into two different condition namely air-conditioned room and open-air workshop. The specimens were evaluated from day one (1) to day seven (7) by tracing the curvature on tracing papers (for springback) and weighing them (for moisture uptake) on a two decimal point balance. Figure 1 summarises the derivation for the radius, r

Where

$$r = \frac{(a^2 + b^2)}{2b} \qquad (1)$$

r - radius,
a - horizontal cross section of (b) and
b - vertical cross section of (a).

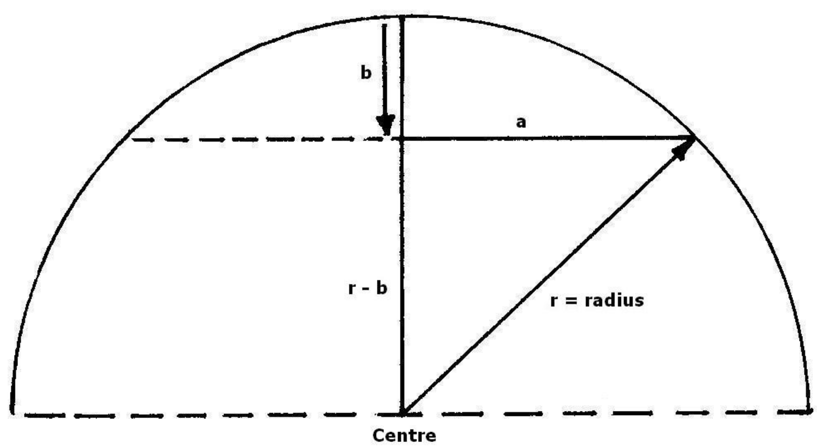

Figure 1. The relative position of parameters r, a and b of a bentwood

Determination of Springback and Moisture Uptake of Bentwood

Bentwood has an inherent tendency to return to its original shape when exposed to high temperature and high relative humidity condition (Steven & Turner, 1970). The extent of these outward movements or the increase in bentwood radius usually referred to as "springback". The value of the springback was calculated based on formula (2).

$$\text{Springback (\%)} = \frac{\text{(Radius at day 7 – Radius at day 1)}}{\text{Radius at day 1}} \times 100 \quad \text{------------- (2)}$$

The increase of the springback is usually caused by the moisture uptake of the woods. As a hygroscopic material, bentwood are expected to absorb moisture from the surrounding. The moisture uptake was calculated based on formula (3).

$$\text{Moisture Uptake (\%)} = \frac{\text{(Weight at day 7 – Weight at day 1)}}{\text{Weight at day 1}} \times 100 \quad \text{---------- (3)}$$

RESULTS AND DISCUSSION

The springback and moisture uptake in the condition of workshop and air-conditioned are presented in Table 1. The results shows that samples for both condition i.e. air-conditioned room and workshop experiences certain percentage in springback and moisture uptake. The values indicated that different radius and thickness have different springback and moisture uptake. Overall samples expose to workshop condition shows highest percentage of moisture uptake and springback.

A bentwood will open out and increase its radius of curvature (springback) if exposed to air of a higher humidity (Steven, 1970). An increase in the moisture content of a bentwood will cause the radius of curvature to increase (springback) (Zhang, 1987). Therefore, bentwood of thickness 15mm and radius 1200 mm shows the highest moisture uptake (10.42 %) and springback (12.60 %) in workshop condition. Whilst the lowest springback (0.48 %) was experiencing under air conditioned room at thickness of 30 mm and radius of 1200 mm. Bentwood with a thickness of 30mm and radius of 600 mm had the lowest moisture uptake (0.19 %) under air conditioned room. This result indicated that condition, thickness and radius were the factors that influenced springback and moisture uptake.

Effect of Bentwood Springback When Exposed in 2 (Two) Different Conditions

Results on the analysis of variance on the effect of bentwood exposure in 2 (two) different conditions are showed in Table 2. There were significant difference in the influences between Condition and Thickness. However there was no significant influence of radius on the springback. The ANOVA for the 2 (two) different conditions carried out in this study is shown in Table 3 according to LSD. The influences of the two conditions significantly effect the occurrence of springback on the wood. The tendency to springback was much greater in workshop condition than in the air-conditioned room. This is mainly because of the high temperature and high relative humidity in the workshop that tends to increase the moisture uptakes by the bentwood. This increases in the radius of curvature of the wood and resulted in springback. Nevertheless, the overall radius of 600 mm, 900 mm and 1200 mm does not have significant difference in the springback since they underwent the same bending treatment process and the number of days in the exposure period.

Table 1. Springback and Moisture Uptake after 7 day of exposure in Air-Conditioned Room and a Workshop

Condition	Radius (mm)	Thickness (mm)	% Springback		% Moisture Uptake	
			Mean	SD	Mean	SD
Air-Conditioned room @ 25 ºC and 70% RH	600	15	4.82	0.64	2.64	0.34
	600	20	3.48	0.13	1.75	0.13
	600	25	2.33	0.44	1.07	0.03
	600	30	1.50	0.08	0.19	0.30
	900	15	4.20	0.10	3.46	0.25
	900	20	2.61	0.13	1.37	0.36
	900	25	1.49	0.09	0.56	0.36
	900	30	1.49	0.079	0.39	0.12
	1200	15	2.35	0.13	1.06	0.14
	1200	20	1.62	0.23	1.42	0.28
	1200	25	1.09	0.17	1.00	0.12
	1200	30	0.48	0.08	0.52	0.08
Workshop @ 23 ºC to 33.5 ºC and 67 % to 96% RH	600	15	9.79	0.73	9.69	0.49
	600	20	7.97	0.55	7.36	1.57
	600	25	7.39	0.16	4.36	0.51
	600	30	5.59	0.20	3.85	0.43
	900	15	11.75	0.30	9.73	0.50
	900	20	8.53	0.38	5.83	1.16
	900	25	6.77	0.25	4.54	0.58
	900	30	4.73	0.21	2.86	0.40
	1200	15	12.60	0.50	10.42	0.08
	1200	20	10.06	0.58	8.93	0.38
	1200	25	6.90	0.82	3.07	0.03
	1200	30	5.53	1.42	2.14	0.05

Notes: Each set of radius and thickness represented by 3 replicates, SD is standard deviations.

Table 2. Analysis of Variance on the Springback in Two Different Condition

Source of variation	Df	F Values	Pr > F
Condition	1	2248.89[b]	0.0001
Radius	2	1.72 ns	0.1906
Thickness	3	233.13[b]	0.0001
Radius x Thickness	6	2.63 [a]	0.0277
Condition x Thickness	3	35.21[b]	0.0001
Condition x Radius	2	43.16[b]	0.0001
Condition x Radius x Thickness	6	7.46[b]	0.0001

Note:

ns : not significant difference at $p<0.05$
a : Indicates significant at $p< 0.05$
b : Indicates highly significant at $p< 0.01$

Table 3. Effect of Conditioning on the Springback

No. samples	Condition	Mean
36	Air-conditined room	2.291[b]
36	workshop	8.133[a]

Note: Means followed by the same letters are not significantly different at $p<0.05$ according to LSD

Effect on Bentwood Moisture Uptake When Exposed to Two Different Conditions

The analysis of variance on the moisture uptakes of the bentwood are showed in Table 4. There were significant differences between the condition of the rooms and the wood thickness on the moisture uptakes. However, there was no significant in the radius of curvature of the bentwood on the moisture uptakes. The two different conditions that indicate the significantly difference which influences the springback is showed in Table 5. This occurred due to the differences in temperature and relative humidity in the workshop condition. The workshop condition experience temperature changes from 23.0 ºC to 33.5 ºC and the relative humidity changes from 67 % to 96 %, and whereas in the air-conditioned room the temperature and relative humidity remained constant at 25 ºC and 70% respectively. The tendency to absorb moisture was much greater in workshop condition than to the air-conditioned room since in the workshop the equilibrium moisture content was higher than in the air-conditioned room. The adsorptive nature of the wood enables it to remove water vapour from the surrounding until it is in moisture equilibrium with the air (John, 1982).

Table 4. Analysis of Variance on the Moisture Uptake in Two Different Conditions

Source of variation	Df	F Values	Pr > F
Condition	1	1618.87[b]	0.0001
Radius	2	2.73 ns	0.0755
Thickness	3	292.14[b]	0.0001
Radius x Thickness	6	7.58[b]	0.0001
Condition x Thickness	3	98.63[b]	0.0001
Condition x Radius	2	4.43[a]	0.0171
Condition x Radius x Thickness	6	12.02[b]	0.0001

Note: ns : not significant difference at $p<0.05$;
a - significant at $p< 0.05$
b - highly significant at $p< 0.01$

Table 5. Effect of Conditioning on the Moisture Uptake

No.of specimens	Condition	Mean
36	Air-conditioned room	1.295[b]
36	Workshop	6.068[a]

Note: Means followed by the same letters are not significantly different at $p<0.05$ according to the LSD

Correlation Between Springback and Moisture Uptakes

Scattered graph in Figure 2 shows a strong relationship between moisture uptakes and springback with 0.88 of coefficient of correlation (R^2). The regression line was represented by the following linear equation

$$Y = 1.0021X + 1.4486 \qquad (4)$$

where, Y is the springback and X is the moisture uptakes.

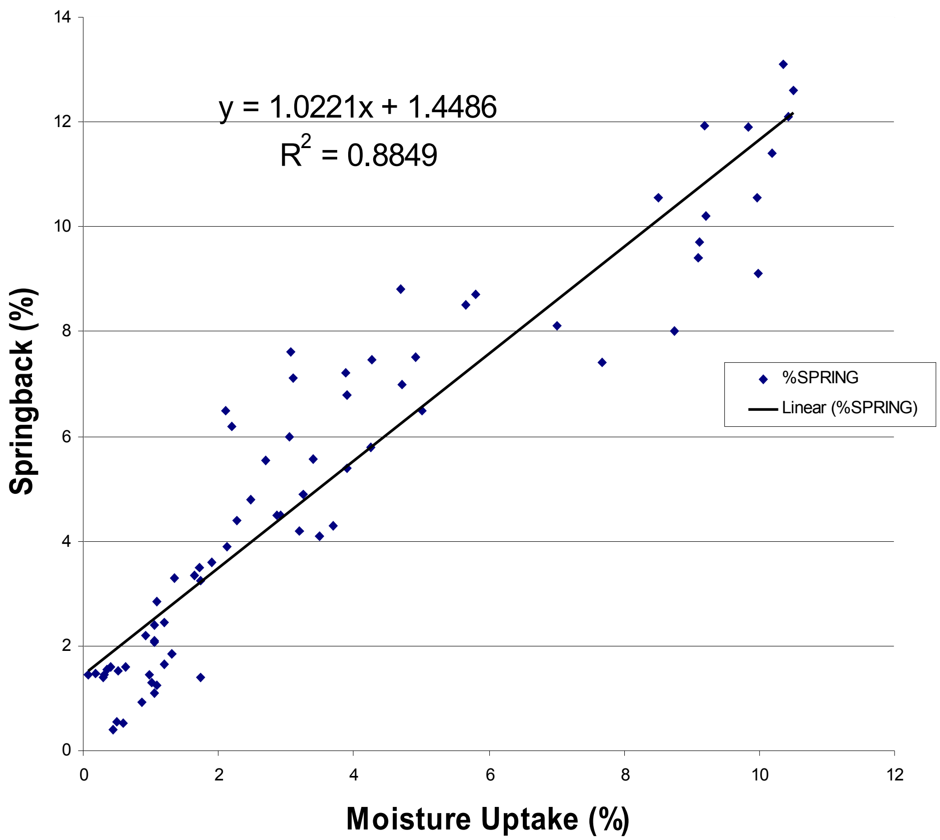

Figure 2. Linear regression of the Springback vs. Moisture Uptake in the bentwood after 7 days of exposure.

This indicates that there is a strong relationship between the moisture uptakes and the springback. The developments of the springback are mostly associated to the uptake of moisture from the surrounding environment. The moisture uptake increases mostly when the bentwood were exposed to the workshop condition rather the air-conditioned room.

CONCLUSIONS

1. Springback in bent rubberwood was influenced by thickness and condition in which they are stored after undergoing bending process.

2. Thick wood specimen tends to exhibit lower springback and lower moisture uptake.

3. Differences in radius of curvature of the wood does not influences springback in bent rubberwood.

4. There were strong relationships between moisture uptake and springback in both the workshop and air-conditioned rooms.

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