VARIATIONS IN MECHANICAL PROPERTIES FOR DIFFERENT CLONES OF *ACACIA* HYBRID PULPS AFTER BEATING

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Abstract: Four-and-a-half years old hybrids of *Acacia mangium* and *Acacia auriculaeformis* from a thinning exercise were studied for pulp and paper strength. The effects of beating on mechanical strength properties of kraft pulp from locally planted *Acacia* hybrid clones were investigated. Kraft pulping processes at 12% active alkali were carried out on all clones. The unbleached pulp were beaten at 1000, 3000, 5000 and 7000 revolutions. The mechanical properties of paper produced determined were tear, tensile and burst strengths and folding endurance. The trends after beating and significance of the changes were also compared. It is hoped for that that the findings from this study can be used to determine the suitability of kraft pulps from *Acacia* hybrid for producing various paper grades.

Keywords: *Acacia* hybrid, Kraft pulp, Beating, Mechanical properties

INTRODUCTION

The potentials of hybrids of *Acacia mangium* and *Acacia auriculaeformis* as raw materials for pulp and paper products were explored in this study. A preliminary study conducted by Sharmiza et al. [1] showed that *Acacia* hybrid to be superior than *Acacia mangium* in terms of mechanical strength. Rufelds [2] reported that the existence of *Acacia* hybrid in Malaysia was first discovered in Sabah in 1971 as a result of natural regeneration after a fire broke out in a plantation where both species were planted close to each other. The hybrid has been observed to attain an improvement in growth [3].

Besides analysing the chemical compositions of fibre sources to determine the properties of paper they will produce, a simulation procedure which imitates the actual converting processes is necessary in pulp and paper research to get an accurate representation of the final product. Pulps, except toilet tissue, blotters and newsprint, are rarely used without beating [4]. Thus, pulps produced in the laboratory are beaten and the hand-sheets produced tested. Beating is carried out to make the paper produced suitable for its intended use. Paper made from unbeaten fibres do not have good formation and are not well bonded. Although beating in general is good, there are some adverse effects on the paper produced such as a decrease in the tearing strength and becoming easily expandable in high humidity.

Beating is a mechanism of applying a light mechanical treatment, via a revolving rotor and a stationery stator, on pulp in the presence of water [5]. Although fibre length plays an important role in determining the strength of paper, inter-fibre bonding is yet another factor to be considered. Beating increases the surface area of adjacent fibres, allowing hydrogen bonds to be developed. However, beating will only increase paper strength if conducted in polar media such as water and alcohols. This is due to the fact that polar media enhance fibre swelling by absorbing the media through the fibre walls. This paper will highlight the variations in mechanical strength of paper in terms of tear, tensile and burst indices as well as the folding endurance.

Tearing strength is the mean force, applied perpendicular to the plane of paper, required to continue the tearing of an initial cut in a single sheet of paper. This property depends highly on the fibre length. The tensile strength is the force required to break a strip of paper by stretching it. The bursting strength is expressed as the maximum uniformly distributed pressure, applied at the right angles to its surface, that a single piece of paper can withstand [6]. The tear, tensile and burst indices are the ratio of these values to the grammage or basis weight of paper. The folding endurance measures the toughness of a paper by the number of 270° folds required to break a piece of paper under load. The folding endurance and tensile and burst strengths are mainly dependant on inter-fibre bonding.

MATERIALS AND METHODS

Acacia hybrid trees at 4 ½ years old were obtained from a thinning exercise in the Sime Darby plantation in Labu, Negeri Sembilan. The clones studied were M2, M5 and C14. Trees with diameter at breast height between 12.1 and 18.5 cm were harvested for this study.

All samples were debarked and chipped using the Taihei chipper. The wood chips were then classified using a chip classifier and the moisture contents determined. 1 kg (dry weight) wood chips were then introduced to the rotary digester for pulping. In this study, the *Acacia* hybrid clones were pulped at 25% sulphidity, 12% active alkali and the liquor to wood ratio used was 3.5:1

The sulphate pulping was carried out at the following conditions:

- Pulping temperature = 170°C
- Time to 170°C = 1 ½ hours
- Time at 170°C = 2 hours

The soften chips were washed, disintegrated and screened to remove shives. Some of the unbleached pulp was then beaten for 20s, 60s, 100s and 140s using the PFI mill. 24g oven-dry equivalent of pulp at 10% consistency was introduced into the PFI Mill. The PFI mill revolved at 3000 rpm. The unbeaten and beaten pulps were the turned into handsheets of 60±3 gsm oven-dry weight. The handsheets were then dried and conditioned at 23±1°C and 50±2% prior to testing.

Table 1 summarises the standard methods used to evaluate the mechanical properties of paper produced. All mechanical properties except number of fold were determined as ratios to the grammage, i.e., in terms of indices. The number of fold was determined using Kohler-Mohlin equipment with 800 g load. Other tests were conducted using Lorentzen & Wettre equipment.

Table 1: Standard Methods Used to Evaluate Mechanical Properties of Paper

No.	Standard Method	
1.	TAPPI 248	Laboratory beating of pulp (PFI Mill method)
2.	ISO 5270: 1998	Pulps-Laboratory sheets – Determination of physical properties
3.	ISO 536: 1995	Paper and board – Determination of grammage
4.	ISO 1924-2: 1994	Paper and board – Determination of tensile properties – part 2: Constant rate of elongation method
5.	ISO 2758: 1983	Paper – Determination of bursting strength
6.	ISO 1974: 1990	Methods of test for paper: Determination of tearing resistance (Elmendorf Method) – First Revision
7.	ISO 5626:1993	Paper – Determination of folding endurance

RESULTS AND DISCUSSIONS

Grant (1961) stated that the tearing strength of paper increases initially and decreases upon further beating mainly due to the shortening of fibre. The graph of tear index versus beating time (Figure 1) showed that the tearing strength of paper from all three clones decreased with beating. An analysis of percent change in all the mechanical properties (Table 2) showed that the maximum reduction was observed on M2 clone (12.8%) and the minimum on M5 clone (4%). The M5 clone showed a slight increase in tearing strength, the M2 clone showed a decrease whilst the C14 clone showed no difference after 20 seconds of beating. These observations are consistent with the fact that fibres are shortened during beating. For M2 and C14 clones, there might be a slight increase in the tearing strength between 0 and 60 seconds of beating time.

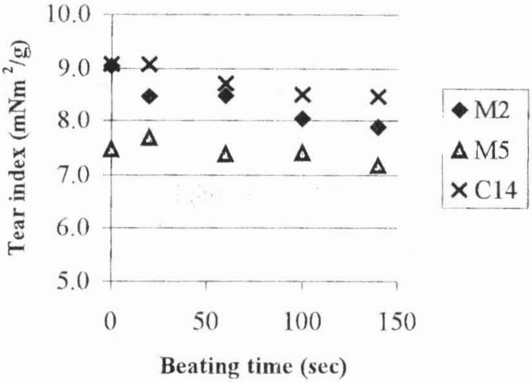

Figure 1: Curve for tear index versus beating time

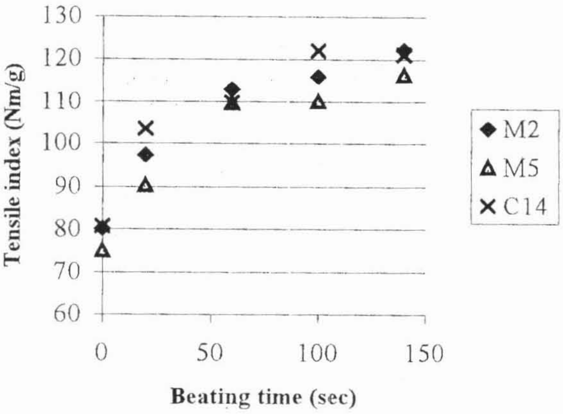

Figure 2: Curve for tensile index versus beating time

Table 2: Percent change in mechanical strength of Acacia hybrid after beating

Clone		M2	M5	C14
	Beating time (sec)			
Tear Index (*mN.m²/g*)	20	-6.4%	2.7%	0.0%
	60	-6.2%	-1.1%	-4.0%
	100	-11.1%	-0.9%	-6.4%
	140	-12.8%	-4.0%	-6.8%
Tensile Index (*Nm/g*)	20	21.2%	20.6%	28.1%
	60	40.7%	46.2%	36.0%
	100	44.7%	46.9%	51.0%
	140	52.3%	55.2%	50.0%
Burst Index (*kPa.m²/g*)	20	57%	50%	61%
	60	89%	79%	92%
	100	100%	94%	100%
	140	112%	106%	111%
Fold (800 K.M.)	20	282%	447%	454%
	60	645%	1144%	1006%
	100	728%	1897%	1203%
	140	1430%	2341%	1667%

Note: Values reported at 60±3 gsm oven dry weight basis of paper. Negative changes indicate decreasing values.
All changes are significantly different at $p<0.05$

The tensile and burst indices increased with beating, as shown in Figures 2 and 3. After 140 seconds of beating time, the tensile strength of the three *Acacia* hybrid clones rose between 50% and 55.2% whereas the burst index showed even larger ascents, between 106% and 112%. Increased inter-fibre bonding are demonstrated by these values. Further beatings are needed to determine the maximum values for both properties. The number of fold increased more than 10 times after only 140 seconds of beating (Figure 4), indicating that the folding endurance of paper is highly dependant on inter-fibre bonding. Beating increases the fibre surface area available for bonding, thus increasing the folding endurance of paper.

The graphs of tensile and burst indices against beating time (Figures 2 and 3) show the strength values levelling off after about 100 seconds of beating. Prolonged beating will show that both properties decreasing as a result of a reduction in fibre length [4]. The folding endurance, however, still showed a rapid increase after 140 seconds of beating, indicating that it is still possible to get higher values upon prolonged beating.

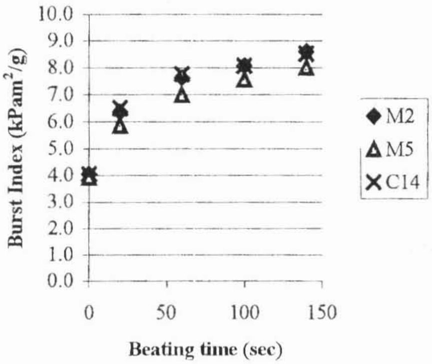

Figure 3: Curve for burst index versus beating time

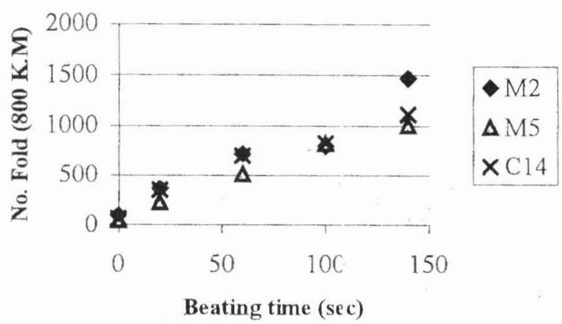

Figure 4: Curve for number of folds versus beating time

From the curves such as shown in Figures 1 to 4, it is possible to predict the maximum values for the mechanical properties. Similar curves are also useful in the manufacturing process due to the possibility to determine the rate at which the pulp properties are developed, consequently controlling the power consumption and output. Depending on the desired products, the beating time that produces the proper balance of the sheet properties can be chosen.

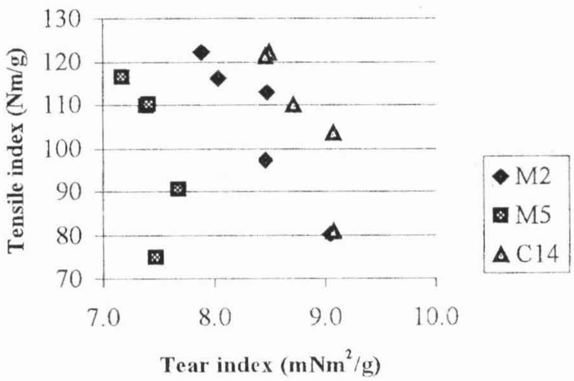

Figure 5: Tensile index versus tear index

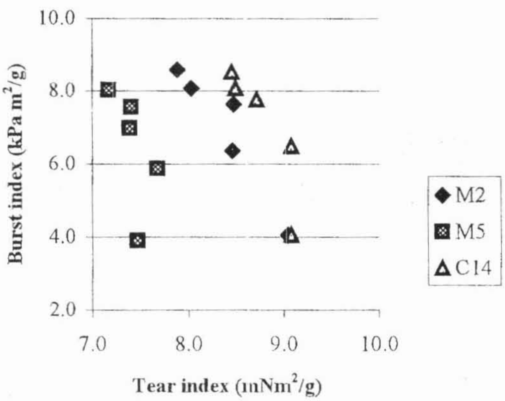

Figure 6: Burst index versus tear index

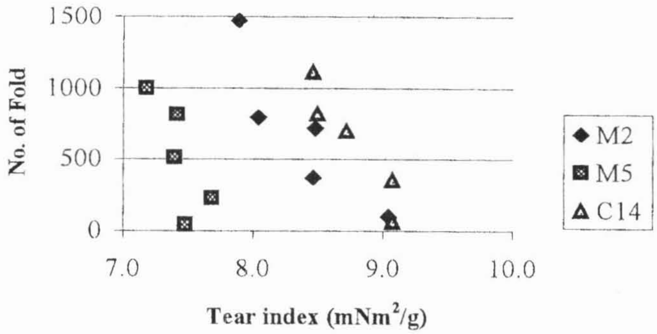

Figure 7: Number of fold versus tear index

The values of tensile and burst strengths, as well as the folding endurance are almost similar for all clones studied when plotted against beating time. The tearing strength showed an exception, with the M5 clone showing lower values compared to the other two clones.

Figures 5 to 7 show the variations of the tensile index, burst index and number of folds with the tear index for all clones. This type of plots is useful to obtain the best possible illustration of relationship between two or more properties. Some paper products, such as the printing grades, good formation is more important than strength, unlike packaging grades which aim for strength.

Table 3: Comparison of mechanical strength between different *Acacia* hybrid clones

Clone	M2	M5	C14
Tensile Index *(Nm/g)*	80.2 n.s	75.1 n.s	80.8 n.s
Burst Index *($kPa.m^2/g$)*	4.0*	3.9*	4.0*
Tear Index *($mN.m^2/g$)*	9.0*	7.5*	9.1*

Note: Values reported at 60±3 gsm oven dry weight basis of paper from unbeaten pulp
* = significant difference at $p<0.05$
n.s = not significant at $p<0.05$

The analysis of variance (ANOVA) carried out at 95% confidence level on all clones showed that the changes in all properties are significant upon beating. The same analysis conducted on mechanical properties of paper made from unbeaten pulp showed that the difference between clones are significant for burst and tear strength, but not for tensile strength (Table 3).

CONCLUSIONS

Beating of pulp prior to papermaking has been used for years to simulate the actual paper converting process. Beating can be used to adjust the properties of paper products to suit their intended uses. Beating induces fibre shortening, promotes fibre bonding as well as good paper formation.

The results of this study showed that beating of pulp decreases the tearing strength of paper, but increases the other mechanical properties. This is due to the fact that beating promotes fibre shortening as exhibited by the tearing strength. The inter-fibre bondings, on the other hand, are increased by beating, thus ascending the tensile and burst strengths and folding endurance of paper.

The analysis of variance showed that except for the tensile strength, both burst and tear strengths were significantly different between the three clones studied. For the beaten pulp, the changes in all the mechanical properties studied were significant with beating.

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