FRACTURE CHARACTERISTICS OF ROUND BAMBOO (*Dendrocalamus asper*) LOADED IN COMPRESSION

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Abstract: A study was conducted to determine the fracture characteristics of round bamboo and their relationship to the strength properties loaded in compression parallel to grain. The species of bamboo used, was "Buloh Betong" (Dendrocalamus asper).The modes of failure were observed to have three types namely splitting and compression (mode 1), multiple failure (mode 2) and compression and end rolling (mode 3). Mode 1 posses the highest strength value The values of Mode 1, Mode 2 and Mode 3 are 69.48 N/mm^2, 68.83 N/mm^2 and 57.25 N/mm^2 respectively. However, statistically the compression strength between mode of failure is not significantly difference. On the other hand, the effects of portion along the length of the culm and between node and internode on compression strength were found to be significant. The compression strength is higher at the top portion compared to the bottom

Keywords: Failure modes, Strength properties, Bamboo species, Portion, Part

INTRODUCTION

The remaining timber and forest areas are decreasing in the next few years. With the new guidelines released by the International Timber Organization (ITTO) and the pressure for Forest Certification procedures for Sustainable Forest Management System, harvesting and utilization of natural stand timbers from the tropical forest are expected to reduced after the year 2000 [9]. The awareness to sustain a green healthy surrounding environment and forest stands had created demand for materials other than timber. With considerations of timber shortages in next few years, alternative material other than timber should be considered. Based on comprehensive study and research activities, bamboo are expected to be a wise alternative material in supporting the increasing demand in the production of wood-based products.

MATERIAL AND METHODS

Buluh Betong (*D. asper*) aged 3 years was used for this study. Fifteen bamboo culms were purchased from FRIM bamboo estate located at Felda Mempaga, Bentong Pahang. The culms were cut at 30 cm above ground level. Each culm was then cut equally into basal (B), middle (M) and top (T) portions of 4 meter length each. The method used for the determination of physical and mechanical properties was based on INBAR standard [4]. The average MC on each specimen was 12%. The average specific gravity was 0.75. After the tests were executed, all the specimens were segregated and grouped according to their mode of failure and was analysed using statistical analysis. Comparison was made between the mode of failure and the strength properties.

RESULTS AND DISCUSSIONS

The analysis of variance for compression test was presented in Table 1. The analysis shows that there are significant differences between portions along the culm height for the compression strength. The values between parts (node and internode) are also significantly different from each other. However, the interaction between portion and part with respect to the compression strength are not significantly different. Table 2 shows the compression strength of *D. asper* at different portion. The results showed that there is an increasing trend in strength properties from bottom to the top for *D. asper*. As stated by Janssen [5], the compressive stress increases from bottom to the top is owing to the increasing in fibre content along the culm height.

Table 1: Summary of analysis of variance on compression strength at different portion and parts of *D. asper*. (Note: * indicates significantly different at p<0.05)

Source	Type III Sum of Squares	df	F	Sig.
Portion	6216.479	2	51.839	.000*
Part	2101.197	1	35.044	.000*
Portion*Part	85.662	2	.714	.491

Table 2: Compression strength of *D. asper* at bottom, middle and top portion

Portion	Mean (N/mm^2)	Std. Deviation
bottom	58.6035	6.72158
middle	72.4205	10.38440
top	74.3092	8.45896

Further analysis of correlation coefficient (r) for the various relationships is given in Table 3. It revealed that the compression parallel to grain (CPL) was negatively correlated with culm diameter (-.656) culm wall thickness (-.796) and part (-.380). Abd. Latif et al. [8] also observed similar trends of variation in *Bambusa blumeana* and *G. scortechinii* for interrelation of CPL with culm diameter and culm wall thickness. The correlation coefficient between CPL with specific gravity and portion were observed to have a positive relationship, where the r-values are 0.196 and 0.573 respectively. It implies that within the culm height from bottom to the top, specific gravity which associated with the relative proportion of vascular bundles and ground tissues was found to increase with the increment of height [3, 5, 8, 10]. Accordingly, it resulted in greater strength as the height increases.

Table 3: Correlation coefficients for CPL, diameter, thickness and specific gravity of compression specimens

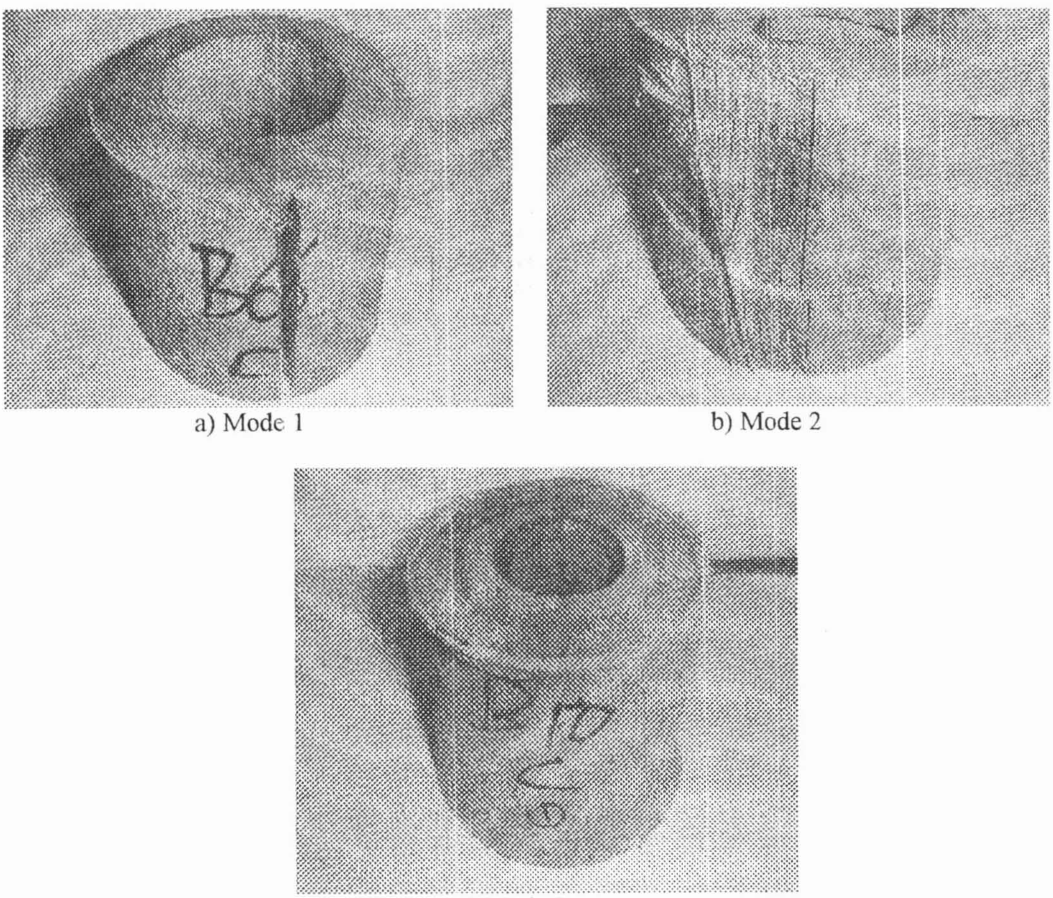
Correlations	CPL	DIA	THICK	SG	Portion	Part
CPL	1					
DIA	-.656**	1				
THICK	-.796**	.802**	1			
SG	.196*	-.255**	-.293**	1		
Portion	.573**	-.856**	-.846**	.220**	1	
Part	-.380**	.274**	.132	-.063	-.040	1

Note: CPL: Compression parallel to grain DIA: Diameter THICK: Thickness SG: Specific gravity
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 3 further reveals that the culm diameter is positively correlated with culm wall thickness (.802) and part (.274). Meanwhile, specific gravity and portion correlate negatively with the diameter (-.255 and -.856 respectively). Somewhat similar trend was observed with the interrelationship between thickness with specific gravity and portion. Otherwise, positive correlation was observed between thickness and part (.132). Similar trend was observed with the correlation between specific gravity and portion where the r-values is .220. However, node and internode correlates negatively with specific gravity (-.063) and portion (-.040).

The analysis of failure mode was performed. Oneway ANOVA was used to analyse the data for mode of failure in relation with their compression strength. From the considerable number of specimen tested, three types of mode of failure were observed at bottom, middle and top for *D. asper*. Splitting and compression was the first mode of failure found (Figure 1a). This mode of failure was found by many researchers such as Meyer and Ekelund [7], Janssen [5], Arce [1] and Espinosa [2]. Janssen reported that the failure is mainly due to splitting particularly due to an excess of the tensile strain of the pectin sticking the fibres together. According to Arce [1], this mode of failure occurred when a critical value of tangential stresses is reached in the outer skin, initiating a longitudinal crack.

Second mode of failure observed (Figure 1b) was multiple failures and are described as a combination of splitting, compression, shear and end rolling. According to Bodig et al. [6], the occurrence of failure in brooming or end rolling types in wood is probably due to the specimen at an elevated moisture content. Another reason for this behavior is improperly cutting of specimen for the test. Third mode of failure (Figure 1c) was observed to occur due to compression and end rolling of the specimen. This type of failure merely occurred at bottom portion of the culm. It is probably due to the thicker culm wall in *D.Asper*. From Table 4, the results showed that the highest compression strength was recorded on mode 1 (69.48 N/mm^2). In mode 2 and 3, the strength value is much lower than mode 1, which is 68.83 N/mm^2 and 57.26 N/mm^2 respectively. Specimen with greater thickness does not represent higher strength. Espinosa [2] stated that the relationship of thickness to strength is not a direct proportion to the increase in bearing surface alone.



a) Mode 1 b) Mode 2

c) Mode 3

Figure 1: Failure mode at macroscopic level for *D. asper* a) Mode 1 b) Mode 2 c) Mode 3

Table 5 summarised the analysis of oneway ANOVA for the relationship between compression strength and their mode of failure at bottom, middle and top portions of *D. asper*. The results indicated that the compression strength of *D. asper* is not significantly different between mode of failure at bottom, middle and top portion of the culm.

Table 4: Means of compression strength of *D. Asper* according to mode.

MODE	Mean (N/mm^2)	Std. Deviation
mode 1	69.4849	11.33384
mode 2	68.8327	10.77930
mode 3	57.2537	4.20692

Table 5: Oneway ANOVA for relationship between compression strength parallel to grain and mode of failure at bottom, middle and top portions of *D. Asper*. (Note: * indicates significantly different at $p<0.05$)

	Sum of Squares	df	F	Sig.
Between mode	563.365	2	2.353	.099

CONCLUSION

The compression strength of *D. asper* was significantly affected by portion along the length of the culm and between node and internodes. The compression strength is higher at the top portion compared to the bottom. The specific gravity (SG) and portion were positively correlated with compression strength parallel to grain (CPL). For *D. asper*, the modes of failure were observed to have three types namely splitting and compression (mode 1), multiple failure (mode 2) and compression and end rolling (mode 3). Mode 1 posses the highest strength value between modes. Statistically, there is no significantly difference between compression strength and mode of failure from bottom, middle and top portion. This implies that there is no relation formulated between compression strength and their mode of failure for this species.

It is recommended that the future research on mode of failure of round bamboo should be conducted on other species since difference species posses different physical, anatomical and mechanical properties. The factor of age also should be taking into account. With the completion of this study, the utilization of bamboo as a structural and composite material could be developed.

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