ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Evaluation on Strength of Chemically Treated 2 and 4 year-old Bamboo *Bambusa vulgaris* through Pressurized Treatment.

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ABSTRACT

Evaluation on the strengths of chemically treated 2 and 4 year-old bamboo Bambusa vulgaris through pressurized process were conducted. The preservatives used in this study were the ammonium-copper-quaternary, copper-chrome-arsenic and mixture of borax-boric acid. The level of chemicals concentrations used were at 2% and 4% respectively. An overall strength reduction occurred after undergoing the treatment process. The strength reduction ranged from 4.9 to 7.6% for ACQ, 5.0 to 7.2% for BBA and 5.9 to 7.9% for CCA treated bamboo. The reductions in the strengths were found to be dependent on the type of preservatives applied, concentration used and their retention in the treated bamboo.
Keywords: Bambusa vulgaris, preservatives, pressurized treatment, strength reduction.

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INTRODUCTION

Bamboo considered to be the best possible alternative material to timber has been known to shows variations in their strength properties. The variations are depending on the species, age, moisture content and position along the culm [1-3]. The bamboo strength are associated with their anatomical structural which are long, thick-walled cells with tapered ends. These strength rely to a large extend on the quality and the quantity of fibres which vary considerably with the bamboo age and position along the culm. The strength properties of bamboo have been investigated by a number of researchers [4]. Bamboo with excellent strength properties is as good as other building material like steel, concrete and timber [5]. An increase in strength is reported to occur when the bamboo reached the age between 3 to 4 years, and thereafter it decreases [1], [6-9]. Thus, maturity period of bamboo may be considered as 3 – 4 years with respect to density and strength. Thus, only mature bamboos are harvested for structural or other heavy-duty uses.

There is a variation in strength with culm height and compressive strength increases with increase of height [1], [8-10], while the bending strength shows the decrease tendency [1], [5], [7], [10-11]. The compressive and bending strength also increases from the inner part of the culm wall to the periphery. Treating bamboo with preservative is intended to increase the life span service of the bamboo and bamboo-based products. However, questions are arises on whether the process treatments will modify the strength properties of the bamboo. Although several studies on strength properties have been conducted but the information on the bamboo strength properties after treatment were not available somehow [4].

The aims of this study were to investigate the mechanical properties between natural untreated and treated bamboo, and to assess the effect of preservatives on the mechanical properties of bamboo. Two basic mechanical properties were carried out as to determine the effects of preservative treatments on *Bambusa. vulgaris* strength properties. These are the compression parallel to the grain and static bending. The studies of the comparative strength properties of chemically treated bamboo were conducted from July 2011 to Feb. 2014 in UMK and FRIM.

MATERIALS AND METHODS

The bamboo culms used in this study were taken from the villages in the district of Jeli, Kelantan, Malaysia. The bamboo were planted by the villagers for their daily usage.

Forty (40) culms of the bamboo *B. vulgaris* culm consist of two-year-old and four-year-old age groups were harvested and used in this study. Each culm was equally cross-cut into three length portions. The samples were divided into three (3) grouping namely, i). the fresh untreated, ii). freshly treated, and iii). field trial blocks. Each sample has a length of 80 cm and diameter between 8 to 12 cm. Chemical treatment were conducted on round bamboo. These samples were than treated chemically with combination of borax and boric acid (BBA) at ratio 1.54:1, copper chrome arsenate (CCA) and ammoniacal copper-quatenary (ACQ) at 2% and 4% by vacuum impregnation processes. Culm samples were placed in the treatment cylinder and treated by pressurized treatment. The treatment cycle adopted is shown in Table 1.

Table 1: The pressurized treatment cycle protocol used in the studies for Means mechanical untreated 2 and 4 year-old *B. vulgaris.*

Initial vacuum	600 mm Hg for 30 minutes (to take the air out of bamboo)
Applied Pressure	12 kg/cm^2 for 2 hours
Final vacuum	600 mm Hg for 30 minutes (to remove the excess preservative)

After treatment, all samples were sliced into strips of 2 cm x thickness x 80 cm length. Samples for grave-yard tests were later resized to 2 cm x thickness x 50 cm. The strength tests of shear, compression parallel to grain and static bending were conducted using the Shimadzu Computer Controlled Universal Testing Machine on split bamboo. The preparation of the test blocks and methods were followed according to the American Standards for Testing Materials [13] with some modification. There is no universal standard method of tests for evaluating the mechanical properties of bamboo. All testing blocks were conditioned to 12% moisture content prior to testing. This was done by placing the test blocks in a conditioning chamber by controlling the relative humidity, temperature and air-circulation for a week until the required equilibrium moisture contents were obtained. The blocks were tested in the split form of size 60 mm (length) x 20 mm (width) x bamboo culm wall thickness for compression and 300 mm (length) x 20 mm (width) x bamboo culm wall thickness for static bending tests.

RESULTS AND DISCUSSION

Natural bamboo culms

The results of the mechanical properties of fresh untreated culms of *B. vulgaris* are presented in Table 2. In general the mechanical tests conducted on the untreated 2 and 4 year old *B. vulgaris* at 12% moisture content indicates that mechanical properties varied with age and culm heights. The four-year-old bamboo possess better strength with an average increased about 4.2% for modulus of rupture (MOR), and 10.3% for compression strength, as compared to two-year-old bamboo. These results were in agreement with previous findings. As bamboo becomes older, the strength increased along with the maturation process. The age is considered to be an important factor influencing the strength properties of bamboo.

Table 2: Means mechanical properties of untreated 2- and 4-year-old *B. vulgaris.*

		Age		Increase in
	Portion	2 Years	*4 Years*	strength*
Compression strength	Bottom	495	531	7.3%
parallel to the grain	Middle	538	609	13.2%
(kg cm^{-2})	Top	629	694	10.4%
	Mean	554	611	10.3%
Bending strength	Bottom	1403	1464	4.3%
(kg cm^{-2})	Middle	1358	1408	3.7%
	Top	1336	1387	4.5%
	Mean	1366	1420	4.2%

* based on 2 year-old value;

The strength of the bamboo was found to increase from 2- to 4-year-old culms. With the exception of the modulus of rupture, the shear, compression parallel to grain, modulus of elasticity and stress at proportional limit increased from 2 year-old culms to 4 year-old culms and from bottom to the top portion of the culms. The increase may be associated with the basic densities, which were found to increase from 2- to 4-year-old culms and from the bottom to the top portion of the culms [4], [13-14].

The height of a bamboo culm has a significant effect on the modulus of rupture. It was observed that the bottom portion is stronger in modulus of rupture than the middle and top portion. Similar observations were also found by other workers [1], [3], [8], [11].

Chemically treated culms

The preservatives retentions of the 2 and 4 year-old treated *B. vulgaris* were presented in Table 3 and the results of the mechanical tests are presented Tables 4 and 5. The analysis of variances for both tests are shown in Table 6. Due to the exhaustive preparation requirements necessary it was decided to carry out only the bending and compression tests on samples treated with ACQ, BBA and CCA at 2 and 4% strength solution by vacuum pressure treatments. The presence of preservatives in *B. vulgaris* after the treatment process slightly decreased the strength properties of the bamboo. From the results obtained in this study, it was observed that there is a pattern variation in the decreases of the strength properties. The variations are dependent on the type of preservative, concentration and the age of the bamboo used. Bamboo blocks treated with ACQ and CCA were found to reduce the bamboo strength properties very slightly more than BBA. The overall results indicate a strength reduction of 4.3 to 9.7% for the ACQ, 4.4 to 10.3 for the BBA and 5.0 to 10.7% for the CCA.

Table 3: Preservative retention (km/m^3) of 2 and 4 year-old of treated bamboo

		AGE	
Chemical	Portion	2 year-old	4 year-old
ACQ (2%)	Bottom	4.96	4.33
	Middle	6.47	4.55
	Top	7.22	5.97
	Mean	6.22	4.95
ACQ (4%)	Bottom	9.16	7.76
	Middle	9.94	7.91
	Top	10.74	9.08
	Mean	9.96	8.25
BBA (2%)	Bottom	4.51	4.22
	Middle	6.32	4.43
	Top	6.91	5.14
	Mean	5.92	4.59
BBA (4%)	Bottom	8.85	7.16
	Middle	9.37	7.67
	Top	10.58	8.23
	Mean	9.61	7.68
CCA (2%)	Bottom	5.64	4.87
	Middle	7.75	4.93
	Top	8.66	5.94
	Mean	7.36	5.25
CCA (4%)	Bottom	10.55	7.21
	Middle	12.17	8.47
	Top	14.54	10.82
	Mean	12.42	8.83

Table 4: Bending strength (MOR) of treated bamboo (kg cm^{-2}).

Chemical	Portion	2 year-old	Strength reduction*	4 year-old	Strength reduction**
ACQ (2%)	Bottom	1299	7.4%	1381	5.7%
	Middle	1267	9.7%	1318	6.4%
	Top	1242	7.0%	1311	5.6%
	Mean	1268	8.0%	1336	5.9%
ACQ (4%)	Bottom	1329	5.2%	1391	5.1%
	Middle	1291	8.1%	1341	4.8%
	Top	1253	6.2%	1327	4.3%
	Mean	1290	6.5%	1353	4.7%
BBA (2%)	Bottom	1311	6.6%	1385	5.4%
	Middle	1259	10.3%	1327	5.8%
	Top	1251	6.4%	1317	5.1%
	Mean	1274	7.8%	1343	5.4%
BBA (4%)	Bottom	1323	5.7%	1399	4.4%
	Middle	1287	8.3%	1336	5.1%
	Top	1262	5.5%	1323	4.6%
	Mean	1291	6.5%	1353	4.7%
CCA (2%)	Bottom	1304	7.1%	1366	6.7%
	Middle	1253	10.7%	1324	6.0%
	Top	1242	7.0%	1303	6.1%
	Mean	1266	8.3%	1331	6.3%
CCA (4%)	Bottom	1327	5.4%	1374	6.2%
	Middle	1276	9.0%	1337	5.0%
	Top	1255	6.1%	1340	5.6%
	Mean	1288	6.8%	1340	5.6%

Table 5: Compression strength of pressurized treated bamboo (kg cm^{-2}).

Chemical	Portion	2 year-old	Strength reduction*	4 year-old	Strength reduction**
ACQ (2%)	Bottom	453	8.5%	493	7.2%
	Middle	502	6.7%	564	7.6%
	Top	573	8.9%	653	6.1%
	Mean	509	8.0%	569	7.0%
ACQ (4%)	Bottom	468	5.5%	496	6.6%
	Middle	504	6.3%	565	7.2%
	Top	581	7.7%	644	7.1%
	Mean	518	6.5%	568	7.0%
BBA (2%)	Bottom	463	6.5%	503	5.3%
	Middle	503	6.5%	579	4.9%
	Top	590	6.2%	656	5.5%
	Mean	519	6.4%	579	5.2%
BBA (4%)	Bottom	472	4.7%	507	4.5%
	Middle	510	5.0%	582	4.4%
	Top	591	6.1%	658	5.2%
	Mean	525	5.3%	582	4.7%
CCA (2%)	Bottom	458	7.5%	499	6.0%
	Middle	504	6.3%	569	6.4%
	Top	583	7.3%	648	6.6%
	Mean	515	7.0%	572	6.3%
CCA (4%)	Bottom	465	6.1%	503	5.3%
	Middle	590	5.2%	575	5.6%
	Top	594	5.6%	654	5.6%
	Mean	523	5.6%	578	5.5%

* based on 2 year-old value of untreated bamboo culms;
** based on 4 year-old values of untreated bamboo culms;

Table 6: Summary Analysis of Variance for bending & compression strength for chemically treated blocks

Type of test	Source of variation	Sum of square	d.f.	Mean square	F-ratio
Static Bending	Age	215082.67	1	215082.67	6644.83 *
Strength	Preservative	3077.12	2	1538.67	47.54 *
	Concentration	13254.45	1	13254.09	409.47 *
	Height	167934.33	2	83967	2594.11 *
Compression	Age	174762.67	1	174762.67	2880.02 *
Strength	Preservative	3627.32	2	1813.50	29.89 *
	Concentration	1350.04	1	1350.07	22.25 *
	Height	683404.18	2	341702.25	5631.12 *

* : significant at $P<0.01$

The 2 year-old culms show slightly higher reduction in strength properties than the 4 year-old culms. The 2 year-old *B. vulgaris* culms show higher amount of preservatives retention than the 4 year-old culms [14]. This may be caused by the water-based fixing salts nature of the of the ACQ and CCA. These two preservative are known to fixed in the cell walls of the bamboo during the treatment process. The fixing process somehow could have some effect on the strength reduction of the bamboo culms. The reduction in strength could occur at the initial stage of the treatment process. As seen in the mechanical tests conducted on the field trial bamboo blocks after 24 months exposure this reduction did not overdo the improved performance of ACQ and CCA treated material compared with the BBA treated blocks.

The strength of *B. vulgaris* was found to increase from the 2 to 4 year-old culms. With the exception of the modulus of rupture, the shear, compression parallel to grain, modulus of elasticity and stress at proportional limit increased from the 2 year-old culms to the 4 year-old culms and from bottom to the top portion of the culms. The increase may be associated with the basic densities, which were found to increase from 2 to 4 year-old culms and from the bottom to the top portion of the culms [1], [13-14]. These results are in agreement with the finding of Janssen [3] and Razak [14]. The height of a bamboo culm has a significant effect on the modulus of rupture. It was observed that the bottom portion was stronger in modulus of rupture than the middle and top portion. Similar observations were also found by other researchers [3], [8], [11], [14].

The presence of preservatives in *B. vulgaris* after the treatment process slightly were decreased the strength properties of the bamboo. From the results obtained in this study, it was observed that there is a pattern variation in the decreases of the strength properties. The variations are dependent on the type of preservative and the age of the bamboo used. Bamboo blocks treated with ACQ and CCA were found to reduce the bamboo strength properties very slightly more than BBA. The overall results indicated that the strength reduction of 4.3 to 9.7% for the ACQ, 4.4 to 10.3 for the BBA and 5.0 to 10.7% for the CCA. The 2 year-old culms showed slightly higher reduction in strength properties than the 4 year-old culms. The 2 year-old *B. vulgaris* culms show higher amount of preservatives retention than the 4 year-old culms. This may be caused by the water-based fixing salts nature of the of the ACQ and CCA. These two preservative are known to fix in the cell walls of the bamboo during the treatment process. The fixing process could have some effect on the strength reduction of the bamboo culms. The reduction in strength occurs at the initial stage of the treatment process. The residual strength in the bamboo will remain almost consistent after the initial reduction in strength if it is use indoor. These strengths might drop slightly if it use in places where there might be expose to the outdoor environment.

CONCLUSION

Natural bamboo

The compression strength tested parallel to the grain increased from bottom to the top portion of the bamboo culms. The strength values of the 4-year-old bamboo culms has an average values between 7.3 to 13.2% higher compared to those from the 2-year-old bamboo culms. The MOR of the bending strength decreased from bottom to top portion of the bamboo culms. The 4-year-old bamboo has higher strength values between 3.7 to 4.5% higher than those of the 2-year-old culms.

Chemical treated bamboo

Bamboo *B. vulgaris* culms treated with preservatives showed a slight reduction in strength properties. The strength reduction however are dependent on the type of preservatives, concentration used, the age of the culms and the amount of chemical preservatives retain in the bamboo during the treatment process. For ACQ type of preservative, the reduction in strength range from 4.3 to 9.7%. For BBA type, it ranges from 4.4 to 10.3% and for CCA type the strength reduction ranging from 5.0 to 10.7% respectively.

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