ASSESSING A METHOD OF BAMBOO TREATMENT AND ITS EFFECTS ON THE DURABILITY AND MECHANICAL PERFORMANCE

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Abstract

Bamboo is a natural material having a fast reproduction and excellent mechanical properties. However, when a natural material in general and bamboo in particular are expected to be a construction material, their durability is always questionable. Indeed, it is well known that these materials do not possess the same performance at the long-term, comparing to industrial materials. A sustainable solution for the bamboo treatment still needs to be investigated. The present study explores the oil-heated treatment with different types of oils like flax or sunflower oils. The present investigation concentrates on mechanical properties and durability of treated bamboos, to assess the effectiveness of this treatment approach. First, bamboo specimens were treated with perspective to increase their durability. Eleven sets with different conditions of treatment were tested: treatment at 100°C or 180°C; with flax oil or sunflower oil, or without oil; treatment time of 1h, 2h or 3h; different cooling methods and cooling times. Then, mechanical and durability tests were carried out on untreated and treated bamboos: uniaxial compression tests, 3 points bending tests, water immersion tests and humidity tests. The results showed that some tested treatment method could increase both the durability and the compressive strength of treated specimens, compared to untreated bamboo.

Keywords:

Bamboo; durability; oil treatment; heat treatment; mechanical characteristics

1 INTRODUCTION

Bamboo is a natural material having a fast reproduction and excellent mechanical properties. The possibility to use bamboo for “green” constructions or to replace steel reinforcements in low-cost houses have been shown in the literature [Moroz 2014]. However, like the most of plant materials, bamboo may be attacked and destroyed by biodegradation factors. There are several existing procedures to improve the bamboo durability but in a lot of cases, chemical treatments were used, which makes the treated bamboo material less environmental friendly. There are also some eco-friendly methods which use thermal and natural products like vegetable oils (palm, sunflower or soy bean) for bamboo treatment ([Li 2015], [Sulaiman 2006], [Wahab 2004]) to improve the durability.

The present paper investigates also the oil-heated treatment with different kinds of oils like flax oil and sunflower oil. However, beside of the durability, influences of the treatment on mechanical properties of bamboo culms will be also studied.

2 MATERIAL AND METHODS

2.1 Materials and treatments

The bamboo used in the present study is from Phyllostachys family, which is present in Europe from early of nineteen century. The specimens were cut at young age (1 year’s old). Different treatment processes were investigated. The main differences come from the heating methods, oils used and the cooling processes. For heating treatment, two ways was tried: specimens were put in an oven or in hot oil. Each set had different heating times. Two types of oil were tested: flax oil and sunflower oil. Finally, specimens were cooled in ambient air or in oil, also with flax oil or sunflower oil. While specimens were cooled in oil, their weights were measured at different moments: 1 h, 12 h, 1 day, 2 days and 3 days. Eleven different sets of bamboo were studied for different treatments and tests (Tab. 1). Each set had also some subsets and each subset had five specimens. After the treatment, bamboo specimens were weighed and stored in ambient air for two weeks and then tested by mechanical tests. In order to assess the oil-absorption of bamboo specimens, there are also specimens which were only treated by oven heating and then cooled in desiccator. Then, the weight of these specimens were determined and compared with that of the specimens treated in oil.

Tab. 1: Different methods of treatment and cooling.

Set	Subset	Treatment method	Treatment duration	Cooling medium	Cooling duration
1	1a	Flax oil, 100°C	1h	Flax oil	24h
	1b		2h		
	1c		3h		
2	2a		1h	Flax oil	1h
	2b		2h		
	2c		3h		
3	3		2h	Flax oil	12h
4	4		2h	Flax oil	72h
5	5a	180°C in oven	1h	Flax oil	24h
	5b		2h		
	5c		3h		
6	6a	Flax oil, 100°C	1h	Ambiant air	12h
	6b		3h		
7	7a	100°C in oven	1h	Flax oil	24h
	7b		2h		
	7c		3h		
8	8a	Sunflower oil, 100°C	1h	Sunflower oil	24h
	8b		2h		
	8c		3h		
9	9a	180°C in oven	1h	Sunflower oil	24h
	9b		2h		
10	10a	100°C in oven	1h	Sunflower oil	24h
	10b		2h		
	10c		3h		
11	11a	Sunflower oil, 180°C	1h	Sunflower oil	24h
	11b		2h		
	11c		3h		

2.2 Mechanical tests

The compressive strengths f_c and the Young's moduli E of specimens were characterized. The compressive strength was measured by uniaxial compression tests on 6cm height specimens and the diameter was the actual bamboo diameter (Fig. 1). The slenderness ratio was about 1.2.

Fig. 1: Uniaxial compression test

The compressive strength was determined by taking into account the real cross-section of bamboo specimens (having internal hollow core).

The Young's modulus was characterized by three points bending testing on 80cm-length specimens. The Young's modulus was just investigated to compare the mechanical characteristics of the used bamboo with that presented in the literature. The relevancy assessment of the studied treatments was only investigated based on the compressive strength.

2.3 Tests under high humidity

In order to test the resistance of treated bamboo to mold growth, specimens of each set was placed in boxes which contained 100% relative humidity (RH). Five untreated bamboo specimens were also tested for the comparison.

Before to be tested under 100% RH, specimens were conditioned in 57% RH boxes for seven days until equilibrium with the 57% humidity rate was reached. Then, specimens were put in 100% RH boxes which were set at 30°C. The bamboo specimens were observed in the 100% HR box during at least 3 days until all specimens had mold exposure symptoms.

2.4 Water immersion test

Another accelerated test for the durability of bamboo is the water immersion test. Before the tests, specimens were also conditioned in 57% RH boxes for seven days. Then the specimens were immersed in water for 10 weeks.

At the end of test, specimens were taken out from water, to see the visible changes and weighed.

2.5 Aging test

An accelerated aging test following Japanese Industrial Standard ("JIS-A treatment" method, [JIS 1994], [Norita 2007]) is also carried out in this investigation. The specimens were immersed in the 70°C hot water for 9h, then, they were observed and weighed.

3 RESULTS

3.1 Effects of oils-treatments on the bamboo properties

Several specimens which had been treated at high temperature (180°C) and then immediately cooled in oil (at 20°C), were cracked due to a sudden change of temperature (Fig. 2). This observation is particularly true for specimens treated in 180°C sunflower oil during three hours. It is suggested that an excessively long heating may deteriorated the bamboo quality.

Fig. 2: Specimens cracked due to sudden change of temperature.

Results from specimens only treated by heat without oil and cooled into the desiccator, showed that a loss in the specimens' weight occurred. This means that some vegetable elements were destroyed during the heating.

That was why the oil-absorption rate for specimens treated in oil could not be evaluated, because the weight changes came from both the micro-structure change (weight decrease) and the oil absorption (weight increase).

3.2 Humidity test

After humidity tests, several specimens were attacked by molds. On specimens treated at 100°C, mold appeared at nearly the same time as on untreated specimens (Fig. 3). This means that a temperature of 100°C is not enough efficient to improve the durability of bamboo. Specimens which had been treated at 180°C (Fig. 4) were less attacked by mold than specimens treated at 100°C. No difference had been seen between the 2 oils at the same temperature (100°C). Molds had grown similarly whatever the cooling way had been. All the bamboos treated at 180°C (in oil or in air) had the same resistance to mold growth. So, it can be suggested that the temperature of treatment is the predominant factor for the mold resistance.

Fig. 3: Set 1- specimens attacked by mold

Fig. 4: Set 5 - specimens less attacked by mold.

3.3 Water immersion test

After 10 weeks immersed in water, treated bamboos did not visibly manifested any significant change on the form. Only the specimens' weights were changed: they increased from 2 to 4%.

3.4 Aging test

The water immersion at 70°C was not enough severe to visibly deteriorate the treated and untreated specimens. Similar to the case of "cool" water immersion, only weight changes were noted, but in this case, the weight increase is more important, from 4 to 21%.

3.5 Mechanical tests

The Young's moduli obtained from three points bending tests were from 8.8 to 9.6 GPa. The variation is due to the quality of different parts on a bamboo tree (bottom or top).These values are in the interval noted in the literature (from 7 to 20 GPa, [Abang 1983]).

Uniaxial compressive tests were to determine the ultimate compressive strength. Observations during the tests confirmed the ductile behavior of bamboo culms. When the specimen reached the maximal stress, only a vertical crack appeared and the specimen was not "exploded" as in the case of other materials (Fig. 5).

The obtained ultimate compressive strengths are illustrated in Fig. 6. Variances were less or more important, from 2 to 30%, depending to each set. It is important to note that, due to a low slenderness ratio (of 1.2), the presented compressive strengths were obtained by multiply the ultimate compressive stresses by a ratio of 0.85, to take into account influences of the frictions between the specimens surfaces and the loading press plates. This phenomenon is well known in mechanical tests and the multiplier is recommended by regulations.

Fig. 5: Specimens after compression tests.

The obtained compressive strength of the untreated specimens was about 60MPa which is in the same order of magnitude of results presented in the literature (38-65 MPa, [Abang 1983]).

For treated specimens, several specimens decreased but several other specimens increased their compressive strengths, especially for the case of set 6 – specimens treated at 100°C with flax oil and cooled in air (6a and 6b) - where an increase up to 40% was noted.

4 DISCUSSION AND CONCLUSIONS

In this paper, a numerous different methods of treatment were investigated: differences in treatment medium (oven, flax oil, sunflower oil), difference in treatment temperature (100°C, 180°C) and in cooling method (oven, flax oil, sunflower oil).

Results showed that the treatment duration influenced properties of treated bamboos. Three hours for treatment at 180°C was too long for the bamboo endurance. One hour or two hours are more convenient for hot oil treatment, not enough long to destroy the bamboo properties.

Form the mechanical view point, set 6 (bamboo treated in 100°C flax oil and cooled in ambient air) had a remarkable strength increase. However, this treatment did not give satisfying results in humidity tests (apparition of molds).

The best compromise was set 9 where specimens were treated by heat without oil, at 180°C (during 1h or 2h) and then cooled in sunflower oil. This method of treatment improve the compressive strength of about 10% and gives a satisfying behavior under durability tests.

Other sets giving acceptable results for all tests were set 5 (180°C in oven during 1 or 2h, then cooled by flax oil) and set 11 (treated at sunflower oil 180°C during 1 or 2h, then cooled by sunflower oil). However, for practice and economic reasons, sets 5 and 9 seem preferable (no use of oil for treatment).

The reasons of good results obtained on sets 5 and 9 may be explained that a relative high temperature destroyed vulnerable elements in the bamboo micro-structure. Then the less-vulnerable material is covered by oil during the cooling, which leads the material to have a better durability.

5 REFERENCES

[Abang 1983] Abang A., Aband A.; Utilization of bamboo as a low cost structural material. Appropriate building materials for low cost housing: African region. Proceedings of a symposium, London, England: E. & F. N. Spoon; p. 177–82.

[JIS 2003] Japanese Industrial Standards; JIS A-5905: 2003 fiberboards. Japanese Standards Association, Tokyo.

[Moroz 2014] Moroz J.G., Lissel S.L., Hagel M.D.; Performance of bamboo reinforced concrete masonry shear walls; Construction and Building Materials 61, 125–137

[Norita 2007] Norita H., Kojima Y., Suzuki S.; The aging effects of water immersion treatments in wet-bending for standardized testing of wood panels.

[Li 2015] Li T., Cheng Da-li, Wålinder M.E.P., Zhou D.; Wettability of oil heat-treated bamboo and bonding strength of laminated bamboo board, Industrial Crops and Products 69; 15–20.

[Sulaiman 2006] O. Sulaiman, R. Hashim, R. Wahab, Z.A. Ismail, H.W. Samsi, A. Mohamed; Evaluation of shear strength of oil treated laminated bamboo; Bioresource Technology 97, 2466–2469.

[Wahab 2004] Wahab R., Samsi H.W., Sudin M, Moktar J.; Strength and durability of bamboo treated through an oil-curing process, Journal of Biological Sciences 4 (5), 658-663.

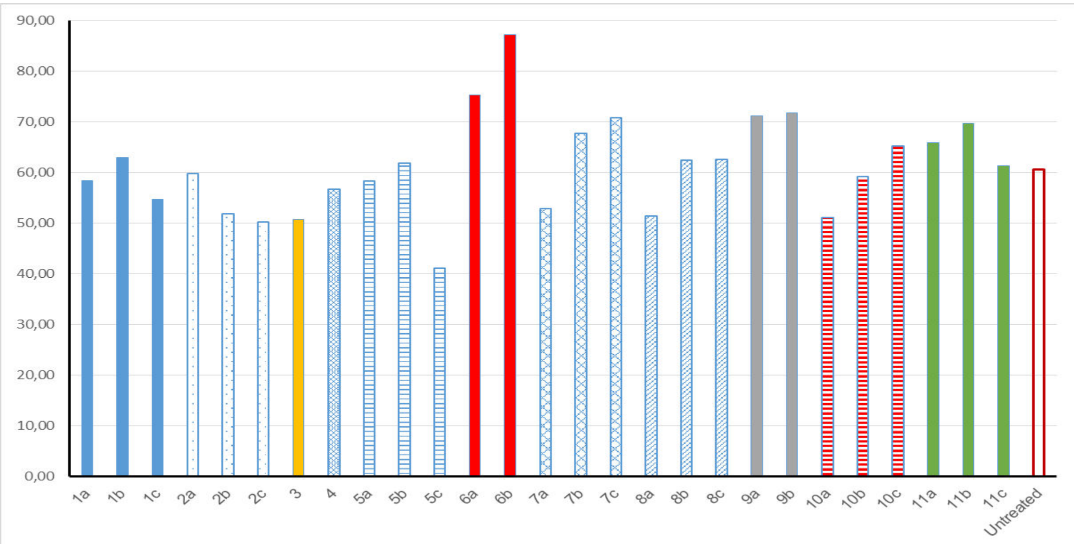

Fig. 6: Ultimate compressive strength obtained.