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EFFECT OF VARIOUS MOISTURE CONTENT ON THE MECHANICAL AND VISCOELASTIC PROPERTIES OF GIANT REED ARUNDO DONAX L.

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Abstract

The giant reed *Arundo donax* L. is an aggressive grass widely diffused throughout warm temperate regions. Thanks to its remarkable features as fast-growing, eco friendly and high specific properties (i.e. high strength/weight and modulus/weight ratios), it is widely used in ancient and traditional buildings, especially in the realization of supports for roof cladding and paneling of walls. A better understanding and a consequent standardization of its properties could make it more suitable for general application in the sustainable building industry. Mechanical and viscoelastic properties of the giant reed were studied as a function of the moisture content. To this scope, various sets of reed were considered. A first set of green reeds was collected in a Sicilian plantation. Another set was fully dried in an oven (103°C for 24 h) and finally a further set was remoistened through soaking in 5%, 10% glucose solutions and HAB (heavy alkylate benzene). For each condition investigated, samples were mechanically tested carrying out stress relaxation experiments in three points bending tests configuration, with the aim of studying the effect of moisture content on the viscoelastic properties of the giant reed. Stress relaxation experimental data were fitted using a mathematical spring pot model in order to characterize the material constitutive law and to capture the two parameter of the model (α and C_α). The experimental results show that it is possible to get a wide range of static (i.e. modulus, strength and ductility) and viscoelastic properties of giant reed by varying the moisture content, making it a suitable material in a wide range of semi structural applications.

Keywords:

Arundo donax; Moisture content; Flexural Properties; Viscoelasticity; Fractional model

1 INTRODUCTION

Arundo Donax L. is a perennial herbaceous grass, widely used all around the world in several application going from musical instrument to rural light weight structures. Its high growing rate and its adaptability to different environmental and climatic conditions lead to have a wide availability to different uses. In rural applications, *Arundo Donax* L. has been used for ancient time to realize fences, stakes for plants and windbreaks [Pilu 2012]. In the last years, the increasing attention in eco friendly and low environment impact materials, leads the industries and the academic community to study the properties of constituents coming from natural resources with the aim of assessing the feasibility of use in unconventional applications. The mechanical characterization of the culm was fully performed [Spatz 1997]. Moreover, in another study [Fiore 2014], *Arundo donax* L. fibres were extracted from the culm to evaluate the chemical, physical and mechanical properties with the purpose to use them in green fibre reinforced material. Moreover, an experimental investigation about its viscoelastic properties was performed, with particular attention to the effect of water soluble extractive [Obataya 2005]. By means of this study was found that there is a linear relationship between the tanδ changes and the extraction condition with variations on the acoustic properties of the material. Viscoelastic behaviour was further studied [Obataya 1998], with regards to the variation of the storage modulus and the mechanical loss tangent. From the avobe, considering that mechanical properties of giant reed were fully clarified, in our study we would try if it is possible to modify its viscoelastic behaviour.

Thus, the aim of this work is to evaluate the possibility of controlling the viscoelastic properties of *Arundo Donax* L. by different treatment to optimize the mechanical behavior for different applications.

2 MATERIALS AND METHODS

In order to evaluate the effect of different treatments on the viscoelastic properties of *Arundo Donax* L., a series of stress relaxation test were performed on the green culms, fully dried untreated culms and after the remoistening process. The plants were collected in a plantation located in western Sicily and selected taking into account the growing age (2 years) so that they presented adult plants features, characterized by heavily lignified vascular bundles (V) embedded in a matrix of amorphous parenchyma (P) (Fig. 1).

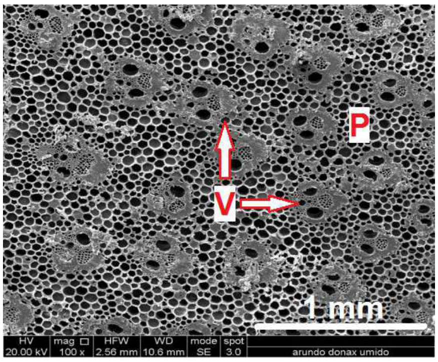

Fig. 1: Cross section of an adult reed internode.

After the selection, the samples were cut from the same zone of the culm (between the 5th and the 6th node) with a length of 230 *mm*, measured and classified as reported in Tab. 1.

Tab. 1: Samples IDs and relative treatment conditions.

Sample ID number	Treatment
1 to 5	None – Green plant
6 to 10	Fully dried
11 to 15	5% glucose solution
16 to 20	10% glucose solution
21 to 25	Heavy Alkylate Benzene (HAB)

In the first phase, green culms were tested immediately after the harvesting. All the remaining samples were oven-dried at 103° for 24 hours to remove the moisture content according to ASABE S358.3 [2012]. Then, a first set of dried samples were tested and the remaining dried samples were remoistened by using glucose solution (5% and 10% concentration) and heavy alkylate benzene in order to modify the viscoelastic properties through fluid absorption. Glucose solutions were chosen because of their compatibility with structure of cane while HAB due to its ability to fix the molecules. An immersion in distilled water was also considered but the data of mechanical tests are not reported here, since the behaviour is unintelligible, owing to the instability of the system distilled water-cell wall. Three point bending relaxation tests (Fig. 2) were performed on each series through the universal testing machine Zwick/Roell Z005 equipped with 5KN load cell. A span of 200 *mm*, a deflection of 1 *mm* and a deflection rate of 1.5 *mm/min* were set (50s to reach the ultimate deflection).

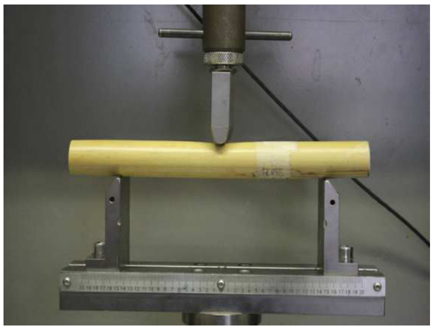

Fig. 2: Three point bending test.

In order to compare the viscoelastic properties of the material, experimental data were fitted to a proper fractional model [Di Paola 2011]. In this model, the viscoelastic behaviour is fully described by an exponential decay law as follow:

$$E(t) = \frac{C_\alpha}{\Gamma(1-\alpha)} t^{-\alpha} \quad (1)$$

where *E(t)* is the relaxation function, $\Gamma(1-\alpha)$ is the Euler Γ function, *t* is the time and C_α and α are two parameter that can be obtained from an analytical-experimental data fitting and that describe the relaxation process. In particular, $\alpha = 1$ corresponds to a pure viscous behaviour and $\alpha = 0$ corresponds to a pure elastic behaviour. Moreover, the effects in term of dimensional variations induced by drying and remoistening processes were evaluated and described.

3 RESULTS AND DISCUSSION

In this section, the results of the experimental tests and the data according to the mentioned fractional model are presented. Tab. 2 shows the effects of the treatment on the moisture content and geometrical feature compared to the fully dried samples. It is clear that as the concentration of glucose is higher as the compatibility of the solution become lower. Concerning the behaviour of the sample treated with HAB, it is possible to notice that the amount of recovered fluids is significantly lower if compared to the other options. This is probably due to the higher viscosity of the Heavy Alkylate Benzene (15,3 cSt at 50°C) that not allows a good capillary motion trough vascular bundles. The stress relaxation behaviour was related to the viscoelastic parameters presented in previous section. Below (Tab. 3) all viscoelastic characteristic parameters are reported. Fig. 3 shows the average curve for the performed relaxation tests for each condition. It is possible to note that all treatment modify the viscous behaviour if compared to the green samples.

Tab. 2: Fluid content and average geometrical variation of whole culm wall compared to the dried sample.

Remoistening process or condition	Fluids content	Outer diameter variation	Thickness variation
Green sample	157,23%	116,01%	115,74%
5% Glucose solution	148,50%	109,97%	109,97%
10% Glucose solution	114%	106,76%	109,90%
HAB	13%	101,21%	100,72%

Comparing this data and taking into account the results reported in Tab. 2, it is possible to assert that the amount of absorbed fluid is related to the viscous behaviour of the material. In particular, as the material is more embedded (see Tab.1 that shows the gain in fluid content) as the value of α parameter is higher and the sample shows a more viscous behaviour. Obviously the fully dried samples show a lower value of α parameter, because of its elastic behaviour. With regards to the samples treated with glucose solutions, it can be observed that an higher percentage of glucose (10%) leads to a more elastic behaviour while an immersion in a 5% glucose solution make the material closest to an viscous media. It is clear that the HAB treatment yields the material more similar to green one even if the fluid absorption is significantly lower if compared to glucose solution treatment. Moreover, HAB could prevent the biological degradation of the cut reed. It is to consider that the stress relaxation occurs, even if in a milder way, on the fully dried samples. This is motivated by the viscoelastic nature of the cell wall. Moreover, about this viscoelastic behaviour, it is important keeping in mind that cell collapse results from the competition between the capillary action (the driving force) and the mechanical behaviour of the cell walls (the resisting force). In particular, the cell collapse is induced by the liquid tension of the free water. It is clear that if the reed is elastic media, no collapse should remain in dry samples because the cells must completely recover their initial shapes after the removal of the load (i.e. free water). However, it can be considered that the shrinkage of the cane actually remains even after the disappearance of free water because the cell wall is viscoelastic. Furthermore, it should be considered that a part of strain is fixed by the temporary rearrangement of amorphous molecules (drying set). This phenomenon remains unless the materials are well softened by proper hygrothermal treatment [Obataya 2005].

Tab. 3: Fluids content and average geometrical variation compared to fully dried samples.

Remoistening process or condition	α	Cα
Green sample	0,032	111,47
5% Glucose solution	0,144	91,74
10% Glucose solution	0,072	51,72
HAB	0,040	105,86
Fully dried	0,025	174,43

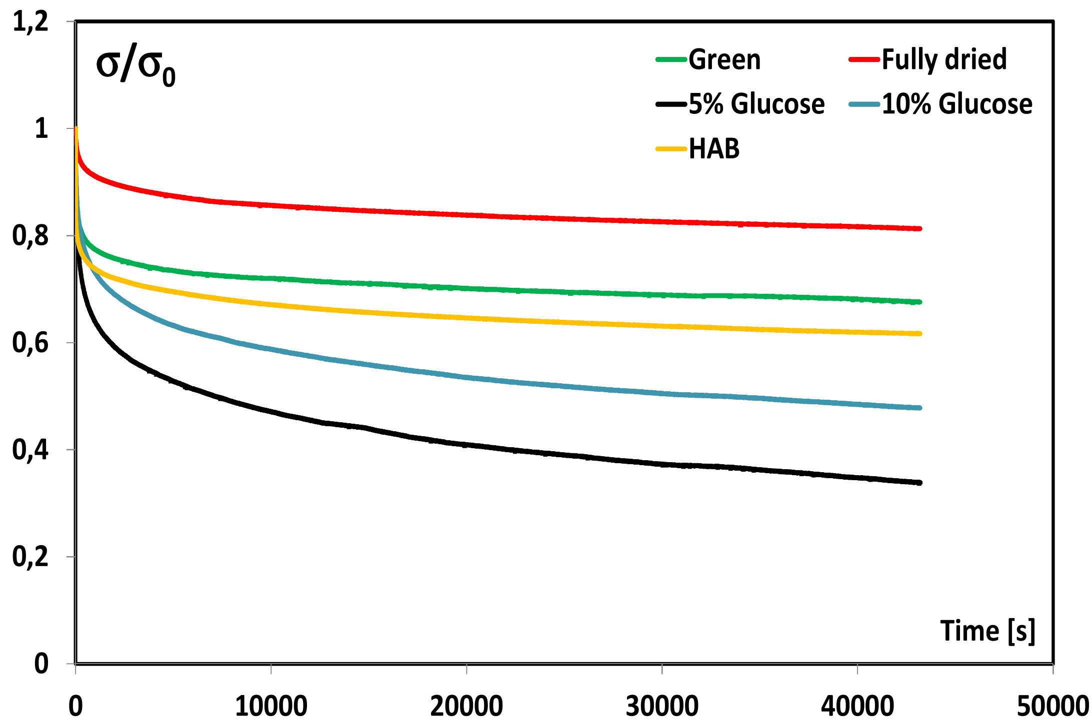

Fig. 3: Comparison between stress relaxation curves of green, fully dried and treated Arundo Donax L. culms.

4 CONCLUSIONS

In this paper stress relaxation phenomena in dependence of remoistening treatment are investigated with the aim of studying the possibility of the modification of viscoelastic properties of giant reed *Arundo Donax* L. In particular three sets of samples (freshly harvested, fully dried and remoistened with 5% and 10% glucose solution and Heavy Alkylate Benzene) were considered and stress-relaxation tests were carried out. The data were fitted to the model proposed by Di Paola, Pirrotta & Valenza [2011] to highlight the differences in terms of viscoelastic behaviour induced by the remoistening process.

The result are concluded as follows:

- the fluid used for the remoistening influences the capillary motion through vascular bundles and the amount of absorbed fluid itself;
- the drying process induces a shrinkage of the section of the samples (i.e. diameters and thickness of the whole cell wall). Otherwise, all the remoistening processes imply a recovery in terms of dimensions;
- all treatments modify the viscous behaviour. In particular dry canes present stress-relaxation phenomena that occur because the cell wall is viscoelastic;
- the use of heavy alkylate benzene yields the material behaviour closer to the green sample behaviour if compared to other treatment, even if the amount of absorbed fluid is lower.

Through this work, the authors put in evidence the effectiveness of a new technical solution, in order to control and standardize the mechanical and hygrothermal properties of the giant reed, with the final aim of rediscovering its use in sustainable rural constructions and in the industry of eco buildings. Modifying its mechanical properties and, in particular, its viscoelastic behaviour, it is possible to reconsider this natural resource for a wider range of application. When the wetting agent leads to a more viscous behavior (case of soaking with glucose solution) of the cane, its utilization could be related to semi structural application as element of load distribution in wood based slab, in which the deflection is one of the main parameters.

In the other case (element closest to elastic media, reachable through an immersion in HAB solution), the cane could be used for strengthening of the panelling of walls in order to improve their seismic behaviour. Hence, an improvement of its performances, combined with the lightness and the tubular shape of its stem, could make it suitable not only because it is environmentally friendly, but also because of its functional performances.

Future goal of this research work is to investigate the influence of glucose concentration and immersion time on the viscoelastic properties with the aim of an univocal control of the properties of *Arundo Donax* L.

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