1 Introduction

This study is a continuation of a research program on non conventional building materials, which is being developed since 1979 at the Civil Engineering Department from the Pontific Catholic University of Rio de Janeiro – PUC-Rio, under orientation of the Professor Khosrow Ghavami.

Every country in the world suffers, in varying degrees, from social, economic and environmental problems. Many countries with deep social and economic problems also have the natural resources, such as bamboo, that could be used to provide an alternative solution in construction, substituting whole or part of expensive imported building materials [1,2]. In more economically developed countries the environmental impact of construction has provided the incentive for the use of alternative materials. “There is overwhelming agreement that the average world temperature is rising, and that it will rise between 1.4 C and 5.8 C over the next 100 years ” [3]. “This global warming is expected to cause flooding to many major coastal cities (Rio de Janeiro, London, Barcelona, New York and others), widespread drought and crop failures in hotter climates such as Asia, Africa and South America” [3]. “The main cause for climate changes is the increase of CO_2 emission into the atmosphere. The effect of greenhouse gases (GHG) and especially CO_2 have no parallel during the last million years of planetary history. From 1958 to 2004, the CO_2 emissions rate reached 1.3% per year and during the last 5 years this increase was closer to 3% a year” [4]. Therefore, the atmospheric concentration value of CO_2 for 2011 is 393.18 ppm [5]. For these reasons, in conjunction with the requirement to reduce the energy demands of the construction industry, researchers are making efforts to develop alternative solutions. Including the use of natural materials in construction. These have the advantage of using lower energy consumption in processing and have less impact on the environment [6], thereby reducing reliance on non-renewable energy resources.

“Many natural materials have exceptional mechanical properties. Timber has strength per unit weight comparable with that of the strongest steels; shell, bone, and antler have toughness values with an order of magnitude greater than engineering ceramics; and mature bamboo stalks have slenderness ratios which are remarkable even by the standards of modern engineering”[7]. For several years bamboo fibres have been recognised and promoted as a renewable construction resource. Bamboo grows quickly, has good mechanical properties, can be grown and processed sustainably for advantageous applications in engineering fields. In construction, the main factor limiting the use of bamboo as concrete reinforcement is its hygroscopic characteristics and smooth surfaces. However, the use of some species of bamboo as reinforcement in concrete structures is considered to be a possible alternative to steel.

"Bamboo is widely available in many tropical and sub-tropical areas of the world. Bamboo's favourable mechanical properties, in particular its high strength to weight ratio compared to other natural and man-made materials, is well known" [7]. Bamboo takes only three to five years to harvest; plants can be repeatedly cropped with sustainable management. The energy needed to produce 1 m^3 per unit of stress in bamboo is 50 times lower than that needed for new steel production [7], and during the production of 1 tonne of steel around 1.8 tonnes (average of all steels) of CO_2 is emitted to the atmosphere [8], whereas bamboo actually absorbs CO_2, and is oxygen producing in its growth.

The use of bamboo as concrete reinforcement has been investigated by many authors [9-30], but only a few [31-34] have studied the mechanics in order to improve the bond stress transfer between bamboo reinforcement and concrete. Lima et al [14] reported that the bond strength of natural (untreated) bamboo within concrete would be 1.53 MPa (concrete compression strength 35MPa). Other authors have investigated treatments that could improve bond strength by adding to the surface of the bamboo asphalt emulsion, coal tar, dilute varnish and water-glass (sodium silicate) [32]. Waterproofing treatments have generally been the most widely studied. Culzoni [31] treated the bamboo surface with a mixture of asphalt emulsion and sand as well as wrapping the bamboo strips with building wire, reaching 2.08 MPa in bond stress. Acha (2002) [35] studied the use of bamboo as a permanent shutter and reinforcement of concrete slabs applying to the bamboo surface a commercial epoxy resin before casting, thus improving the bond stress to 2.75 MPa.

In this study, based on the results of bamboo surface treatment using epoxy resin [35] developed at PUC-Rio (Brazil), experimental and theoretical analyses were executed at the University of Bath and University of Cambridge (England). Under investigation in the experimental program was considered:

- 32 push-out test specimens of surface treated bamboo strips (for reinforcing concrete) were prepared and tested. The influence of the resin type, gravel size (2 or 4 mm), bamboo node and procedures for cleaning the surface of the bamboo on the bond–slip curves obtained is analysed. The treatments improved the natural bond stress of bamboo when embedded in concrete on average 4.5 times more. As well as improving waterproofing of the bamboo (chapter 3);

- A full scale (3000 mm by 3000 mm) two-way spanning concrete slab reinforced with bamboo strips (without any shear reinforcement) was constructed. The experimental test was simply supported along its four sides and subjected to a central concentrated load. A finite element model was created using SAP2000 to analyse and design the bamboo reinforcement (using DELCAR). Experimental failure load was found to be approximately 148.39 % and 110.91 % of the theoretically predicted values by FEM and by ultimate punching shear load following BS 8110 [36] respectability. The slabs exhibited high stiffness against deformation prior to collapse through punching shear load (chapter 4);

- Also with the intention of produce laminated bamboo strips or bars (using the bamboo surface treatment) with higher mechanical properties than just the plain bamboo culm strips used for concrete reinforcement, an experimental investigation of the effect of moisture content at room temperature and frozen conditions on Bamboo *Dendrocalamus giganteus (DG)* layers with highest fibre volume fraction (V_f) was carried out (testing the tensile strength and compression strength of these layers on 2250 specimens). The absorption of water, mechanical properties of bamboo layers and failure were analyzed in detail and appropriate mathematical equations have been established. It was shown that the increase of water particles weakens the bamboo polymers which results in the deterioration of the interface bonding between the DG bamboo fibres and the xylem (matrix) resulting in the loss of strength, modulus of elasticity and further deformation. Rapidly decreasing properties are observed up to 23% moisture content. The results show that *Dendrocalamus giganteus (DG)* bamboo layers with highest fibres volume fraction (V_f) and low moisture content can be applied in composite materials for construction and others engineering applications (chapter 5).

Finally a potential application for using the new material for concrete reinforcement is presented comparing its mechanical properties with the requirements of hydroelectric plant structures (Appendix I).

It can be concluded that the bamboo surface treatment using epoxy resin is adequate to enhance bonding and increase rugosity between bamboo and concrete. Bamboo culm strips and laminate bamboo strips or bars with surface treatment and moisture content between ~0% to ~3% have a high performance for use as concrete reinforcement, providing a new alternative for construction use.