Pontifícia Universidade Católica
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Bamboo: High Tech Material for Concrete Reinforcement

TESE DE DOUTORADO

Thesis presented to the Programa de Pós-Graduação em Engenharia Civil of the Departamento de Engenharia Civil, PUC-Rio as partial fulfillment of the requirements for the degree of Doutor em Engenharia Civil.

Advisor: Prof. Khosrow Ghavami

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The author is graduated in Civil Engineering at Federal University of Sao Carlos-SP (UFSCar-1999), specialized in structures systems. He got his MSc at Pontifical Catholic University of Rio de Janeiro (PUC-Rio-2002), studying Bamboo Permanent Shutter Concrete Slab. Previously his PhD studies, Eduardo has worked developing a computational routing for long-term test of structural elements on the "Intelligent Concrete" project at Imperial College London (2003) and on the experimental polyester tensile test to temperature time prediction method for floating platforms at University of Cambridge (2004). He is a consulter in the numerical analyses of hydroelectric structures and research member of Non-conventional Materials and Technologies group (NOCMAT). The author has developed this thesis at PUC-Rio, University of Cambridge and University of Bath

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To my silence

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To all of my family for the education, orientation and love.

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Abstract

Acha Navarro, Eduardo Humberto; Ghavami, Khosrow (Advisor). **Bamboo: High Tech Material for Concrete Reinforcement.** Rio de Janeiro, 2011. 138p. Dr. Thesis-Departamento de Engenharia Civil, Pontificia Universdade Catolica do Rio de Janeiro.

In this study, based on the results of bamboo surface treatment for concrete reinforcement developed at PUC-Rio (Brazil), theoretical and experimental analyses were executed at the University of Cambridge and University of Bath (England). To improve the bamboo surface treatment (using epoxy resin) an experimental program concerning 32 push-out specimens were carried out. Bamboo strips (for reinforcing concrete) prepared from Phyllostachys Pubescens bamboo and treated to enhance surface bonding were used, with a constant embedment length of 20 mm. The influence of two resins type, gravel size (2 or 4 mm), bamboo node and procedures for cleaning the surface of the bamboo on the bond–slip curves obtained are analyzed. Using the best bamboo surface treatment a full scale (3000 mm by 3000 mm) two-way spanning concrete slab reinforced with bamboo strips (without any shear reinforcement) was constructed and tested. 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. Experimental failure load was found to be approximately 148.39 % and 110.91 % of the theoretically predicted values by the numerical model 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. Finally, to produce an advanced bamboo composite material 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) were considered. 2250 tensile and compression test specimens were tested. The absorption of water, mechanical properties of bamboo layers and failure were analyzed in detail and appropriate mathematical equations have been established. From the results the tensile strength and tensile modulus of elasticity (TMOE) of DG bamboo fibres were estimated. The results show that

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Dendrocalamus giganteus (DG) bamboo layers with highest fibres volume fraction (V_f) and low moisture content can be applied in composite materials for construction, energy field (structural parts of wind turbine blades), automotive field (car structures), and aviation (small aircraft) providing a new low carbon alternative material.

Keywords

Bamboo; Concrete reinforcement; slabs; Biomaterials

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Resumo

Acha Navarro, Eduardo Humberto; Ghavami, Khosrow (Advisor). **Bambu: Material "High Tech" como Reforco em Concreto.** Rio de Janeiro, 2011. 138p. Dr. Tese -Departamento de Engenharia Civil, Pontificia Universdade Catolica do Rio de Janeiro.

Em este estudo, com base nos resultados do tratamento da superfície do bambu para reforço de concreto desenvolvido na PUC-Rio (Brasil), análises teóricas e experimentais foram executados na University of Cambridge e University of Bath (Inglaterra). Para melhorar o tratamento da superfície do bambu (usando resina epóxi), um programa experimental sobre 32 espécimes de Push-out foram realizadas. Tiras de bambu (para concreto armado) preparadas a partir de bambu Phyllostachys pubescens e tratados para melhorar a aderência foram utilizados, com um comprimento embutido de 20 mm. A influência do tipo de resina, tamanho do agregado (2 mm ou 4 mm), nó do bambu e os procedimentos para limpar a sua superfície foram obtidas é analisadas em curvas de aderência-deslizamento. Usando o tratamento com melhores resultados uma laje de concreto (3000 mm x 3000 mm) reforçada nas duas direções com tiras de bambu (sem armadura de cisalhamento) foi construída e testada. A laje foi testada simplesmente apoiada nos quatro lados com carga concentrada no meio. Um modelo de elementos finitos (MEF) foi criado usando SAP2000 para analisar e projetar o reforço de bambu. A carga experimental de colapso foi aproximadamente 148,39% e 110,91% dos valores teoricamente previstos pelo modelo numérico e pela carga máxima de punção (seguindo BS 8110 [36]) respeitabilidade. A laje apresentou alta rigidez contra a deformação antes do colapso por punção. Finalmente, para produzir um material composto avançado usando bambu para reforço de concreto, investigações experimentais do efeito do teor de umidade à temperatura ambiente e em condições de congelamento do bambu *Dendrocalamus giganteus (DG)* foram realizadas. Laminas de bambu com maior fração volumétrica de fibras (Vf) foram consideradas. 2250 corpos de prova de tração e compressão foram testados. A absorção de água, propriedades mecânicas das laminas de bambu e colapsos foram analisados em detalhe, e adequadas equações matemáticas foram estabelecidas. A partir dos resultados da

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resistência e módulo de elasticidade à tração (TMOE) da fibra de bambu DG foram estimados. Os resultados mostraram que as laminas de *Dendrocalamus giganteus (DG)* com maior fração volumétrica de fibras (Vf) e baixa umidade podem ser aplicadas em materiais compósitos para a construção, campo de energia (peças estruturais das hastes de turbinas eólicas), área automotiva (estruturas de carros), e aeronáutica (aviões de pequeno porte), fornecendo um novo material alternativo de baixo consumo de carbono.

Palavras-chave

Bambu; reforço para concreto;lajes; biomateriais

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Contens

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List of symbols and abbreviation

%	Percent
fc	The compressive stress
Ec	Young's modulus strength of concrete
E_b	Young's modulus strength of bamboo
σ_t	Tension strength of bamboo
f_t	Tension strength of concrete
ε_c	Strain of concrete
σ_c	Compression strength of concrete
σ_b	Tension strength of bamboo
ε_b	Strain of bamboo
N_{cf}	Design value of compressive normal force in the flange
f_{ck}	Compressive strength of concrete
γ_c	Partial factor for concrete
f_{yp}	Steel tensile strength
γ_{ap}	Partial safety factor for the profiled steel deck
A_p	Area of steel
f_k	Compressive strength of concrete
f_{yp}	Steel tensile strength
v	Shear stress
P_{ult}	Ultimate load
f_{ck}	Concrete characteristic strength
με	Micro strain
p_i	Inner perimeter
p_e	External perimeter
ºC	Celsius degree
l_c	Embedment length
f_c'	Concrete compressive strength of the control cube specimens
τ_{max}	Bond strength
τ^*_{max}	Normalised bond strength
M_{ult}	Ultimate moment per unit width of slab.
P_{cr}	First crack load

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P_{ul}	Failure load
P'_{cr}	First theoretical crack load
‰	Per thousand
δ	Vertical deflection
q	Distributed load
V_f	Fibre volume fraction
A_f	Area of fibres
A_l	Walls cross-section were measured
M_c	Moisture content
σ_{TE}	Tensile strength at the elastic region
TMOE	Tensile modulus of elasticity

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People are illogical, unreasonable, and self-centered.
Love them anyway.

If you do good, people will accuse you of selfish ulterior motives.
Do good anyway.

If you are successful, you win false friends and true enemies.
Succeed anyway.

The good you do today will be forgotten tomorrow.
Do good anyway.

Honesty and frankness make you vulnerable.
Be honest and frank anyway.

The biggest men and women with the biggest ideas can be shot down by the smallest men and women with the smallest minds.
Think big anyway.

People favor underdogs but follow only top dogs.
Fight for a few underdogs anyway.

What you spend years building may be destroyed overnight.
Build anyway.

People really need help but may attack you if you do help them.
Help people anyway.

Give the world the best you have and you'll get kicked in the teeth.
Give the world the best you have anyway.

by Dr. Kent M. Keith

In the final analysis, it is between you and *your* God. It was never between you and them anyway.

by Mother Teresa

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