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Comparative Analysis of Flexural Capacity of Bamboo Reinforced and Conventional Steel Reinforced Concrete Beams Through Numerical Evaluation

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ABSTRACT. *Steel reinforcement bars are commonly used in the building industry, but their production contributes to toxic waste and emissions. Bamboo is being marketed as a sustainable alternative due to its low cost and tensile strength. It is a readily available natural material that can potentially replace steel as a conventional reinforcement. The idea of hybrid beams (50% bamboo and 50% steel) was developed to get equal outcomes in terms of the structural reaction, and ABAQUS was used to develop a set of beams. By using conventional dimensions and material qualities, a total of five beams were modelled. According to the analysis, the maximum displacements for each beam would be different. The load-displacement curve of five beams was obtained and it was determined that when combined with steel, bamboo may partially replace it.*

Keywords: Bamboo, Green Building Material, Hybrid, Reinforcement.

1. INTRODUCTION

The construction industry is a significant contributor to environmental pollution due to the use of materials such as concrete, steel, and ceramics. Bamboo is a promising alternative to steel in reinforced concrete, as it is sustainable and environmentally friendly building material. Bamboo is a quick-renewing plant with a faster growth rate than trees and can be used as a sustainable supply for the building industry. However, bamboo must be treated to protect it from moisture, pests, and temperature. Despite the lack of detailed data and stress calculations from experiments on bamboo reinforcement, its potential ecological benefits make it a worthwhile consideration for use in construction, particularly in areas where the availability of steel is limited. It's important to invest in sustainable alternatives to avoid importing raw materials in large quantities to fulfil the rising demand for reinforcing steel by the building industry.

Studies have shown that bamboo-reinforced concrete (BRC) has potential benefits in terms of durability, mechanical properties, and environmental friendliness when compared to steel-reinforced concrete (SRC) (1). Bamboo has higher tensile strength than compression and reaches its maximum strength at the age of three to five years (2,3). Another study states that corrugated bamboo is beneficial to avoid bond slip and offer enough flexural capacity (4). However, there is a lack of detailed data and strength analysis of bamboo reinforcement, and more research is needed to fully understand the potential use of bamboo as a reinforcement material in construction industry, and to analyze the behavior under different loading conditions. The goal of the present study is to determine the amount of bamboo that can replace steel by comparing the load-deflection curve of different numerical models.

2. METHODS AND MATERIALS

The behavior of different combinations of beams was modelled using the suitable simulation technology, ABAQUS/CAE 2020 finite element modelling. The following five beams shown in **Error! Reference source not found.**, were modelled with a different set of reinforcement having longitudinal bars or both longitudinal bars and stirrups using Finite Element Modelling to determine the beam that provides the realistic results.

Table -1: Models Properties

Model Name	Specimen	Model Description
M1	Steel	Doubly reinforced beam with steel bars and steel stirrups
M2	Bamboo	Doubly reinforced beam with bamboo bars only
M3	Bamboo	Doubly reinforced beam with bamboo bars and bamboo stirrup
M4	Bamboo and steel	Doubly reinforced beam with bamboo bars and steel stirrups
M5	Bamboo and steel	Doubly reinforced beam with 50% steel and 50% Bamboo.

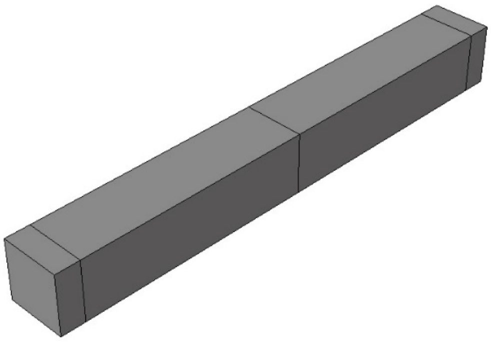

Fig 1-a: Concrete Beam of all Models.

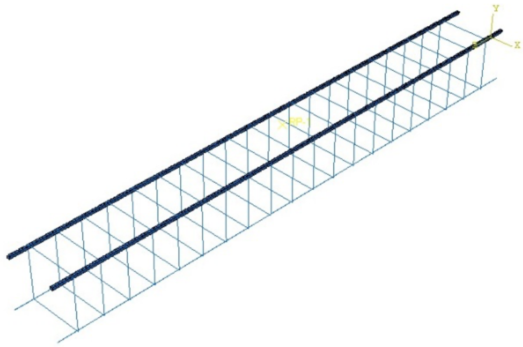

Fig 1-b: Model of M5 (**Error! Reference source not found.**).

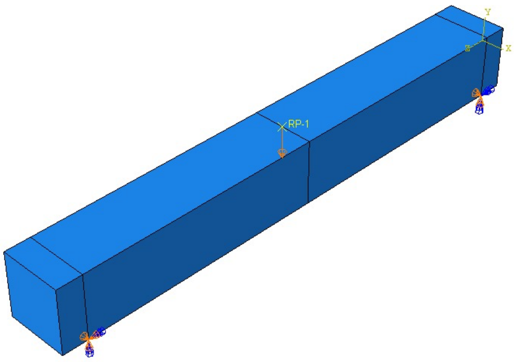

Fig 1-c: Kinematic Coupling on the Beam.

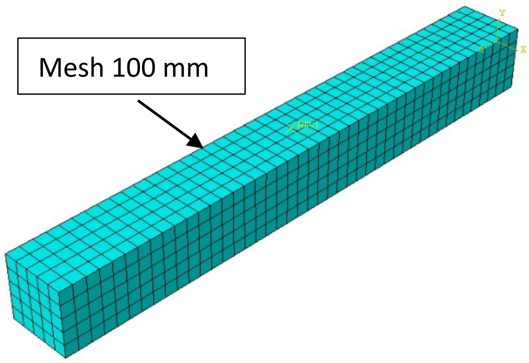

Fig 1-d: Meshed Profile of Beam.

Properties from previous studies (5–7) such as mechanical and material were used to model the behaviour of their respective properties, as demonstrated in Table 2.

Table -2: Mechanical and Material Properties.

Material	Density(ρ) (Kg/m)	Elastic Modulus (MPa)	Poisson ratio(v)	Ultimate compressive strength (MPa)	Ultimate tensile strength (MPa)
Bamboo	700	17200	0.15	150	225
Concrete	2300	33600	0.15	31.31	3.13
Steel	7850	200000	0.3	172.3	400

This research uses corrugated bamboo of 4180x20x20 mm geometry for the simulation. Figure 2 shows the geometry of corrugated bamboo.

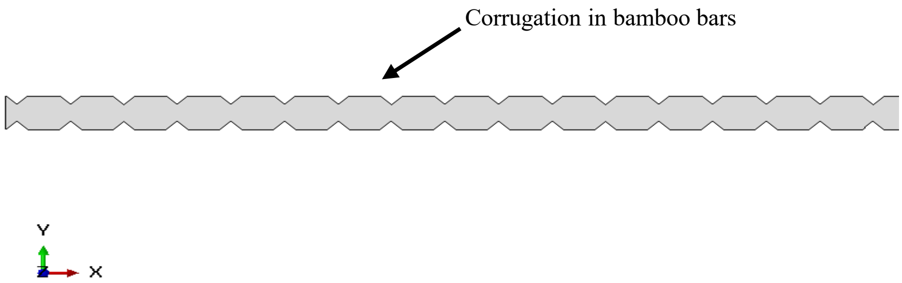

Fig -2: Corrugated Bamboo used for Modelling.

The concrete damaged plasticity model (CDP), which offers a general capability for modelling concrete and other quasi-brittle materials, was used in finite element modelling to define the inelastic behavior of concrete (8). The parameters used for concrete-damaged plasticity (9) for modelling is shown in Table 3.

Table 3: CDP Parameters (9)

Dilation Angle	40
Eccentricity	0.1
Compressive strength of concrete, f'_c	18 MPa
Poisson ratio of concrete (v)	0.15
$\boldsymbol{fb_o/fc_o}$	1.16
K	0.67
Viscosity Parameter	0

The beams are designed against loading conditions and in the absence of such information this study provided the minimum reinforcement as per design code requirements. The formula used to calculate the minimum area of steel is according to ACI standards:

$$A_s)_{min} = \frac{1.4}{f_y} b_w \qquad (1)$$

The values of the parameters used are $b_w = 500\ mm$, d = 460 mm and $f_y = 300\ MPa$. The number of the bars provided will be equal to the number of bars provided in all the other four models. The bamboo reinforcement was selected based on the design of steel reinforcement. The steel reinforcement was replaced with an equal amount of bamboo for fair comparison.

The embedded region method of the Abaqus FEM program was used to model the bond between concrete and bamboo reinforcement. It overcomes mesh restriction problems and evaluates the stiffness of reinforcement independently from concrete elements. The host (concrete) and slave (bamboo bars) elements are perfectly linked. However, the model requires more computation time and cost. The capacity curve was obtained by applying displacement-controlled loading at a reference position, which resulted in the load vs displacement curve at the reference position using the kinematic coupling technique shown in Figure 1-c.

3. RESULTS

Load displacement curves of all the models described in **Error! Reference source not found.** are obtained after performing finite element modeling using Abaqus 2020. These curves are represented on the same graph as shown in Chart 1. Percentage reduction in strength of all models as compared with M1 is shown in Chart 2. The curve of M1 represents the load-deflection curve of the doubly reinforced beam with steel bars and steel stirrups and is considered as the reference beam to compare with all other modelled beams. The curve of M2 represents the load-deflection curve of the doubly reinforced beam with bamboo bars only and the ultimate strength of this model is 47% less than the model M1. The curve of M3 represents the load-deflection curve of the doubly reinforced beam with bamboo bars and bamboo stirrups and the ultimate strength of this model is 46% less than that of model M1. The curve of M4 represents the load-deflection curve of the doubly reinforced beam with bamboo bars and steel stirrups and the ultimate strength of this model is 49% less than M1. It shows that there are no significant changes in the strength of the beam by just replacing the bamboo stirrups with steel stirrups as the stirrups are only used to hold the primary reinforcement bars properly which only helps to resist diagonal shear cracks. Load-deflection curves of models M2 and M4 shows similar behavior which suggests that bamboo reinforcement cannot be used as longitudinal reinforcement with or without stirrups. Furthermore, the curve of M5 represents the load-deflection curve of the reinforced beam with 50% steel and 50% bamboo and the ultimate strength of this model is only 7% less than model M1. This hybrid beam shows an increase in the strength of 40%, 39%, and 42% as compared to the M2, M3, and M4 models respectively.

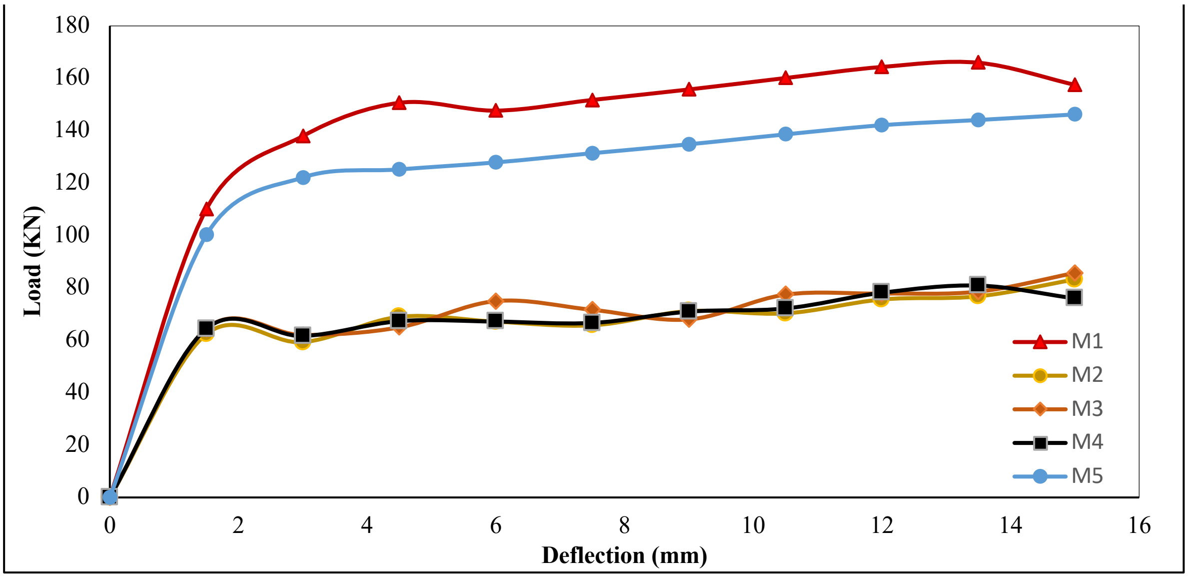

Chart -1: Load Deflection Curve of all Models represented in **Error! Reference source not found.**

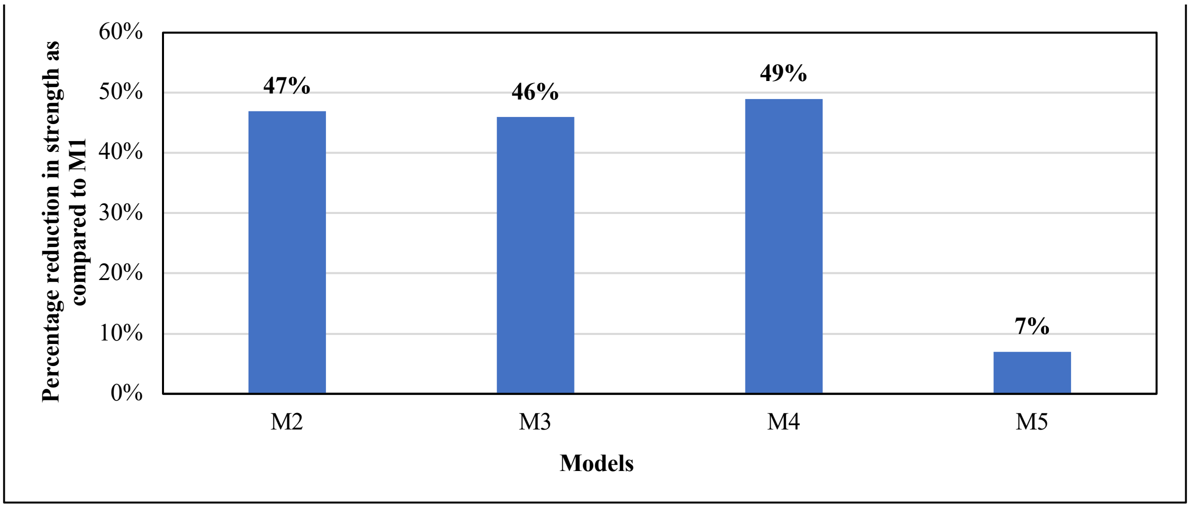

Chart -2: Represents the Percentage Reduction in Strength of all Models as compared with M1.

4. CONCLUSION

Based on numerical tests conducted, the following conclusions are drawn from the research:

- Due to the difference between the low stiffness and overall strengths of bamboo, the comparative research showed that having bamboo as the only reinforcement might not be able to achieve the same results as a typical beam having steel reinforcement.
- However, reinforced beams with 50% steel and 50% bamboo have ultimate strength which is only 7% less than the beam with steel as only reinforcement. Therefore, this beam can be used in the construction industry resulting in a decrease of 50% in demand for steel.

Further experiments are needed to verify the preliminary results presented. Investigating the combination of bamboo and steel reinforcement and adding steel fiber to the beam for greater strength, are recommended for further analysis.

5. ACKNOWLEDGEMENT

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