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EXPERIMENTAL INVESTIGATION AND DESIGN OF BAMBOO REINFORCED COMPOSITE ORTHOSIS USING GENETIC ALGORITHM

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ABSRACT

Prosthetic leg compensates for the limb loss by providing structural strength and anatomic mobility to amputees. It uses composite shafts and hollow metal tubes to join knee and foot prosthetics. Such orthotics play the role of tibia bone in artificial limb. While most extremities are designed either for light activity with Solid Ankle Cushioned Heel (S.A.C.H.) foot or for atheletic performance with Flex-Foot, only few orthotics are designed robust enough to be used in both activity levels. Incorporating a bimimetic approach, we have developed a bamboo reinforced composite shaft which is structurally equivalent to a tibia in natural leg. Volume fraction of reinforcement to maximize the strength of composite was found by solving the stress equation under iso-strain condition. Genetic algorithm used to solve stress equarion is inspired by natural selection process and random genetic drift in skeletal traits of human body. Locally available bamboo was cut in the form of sticks to reinforce epoxy matix. Critical bending moment of the orthosis was found to be 2.75 times higher than that on natural tibia under 3 point flexion test, hence validating robustness of Bamboo Reinforced composite shaft in both light and atheletic activity levels with maximum flexural strength of 83.39 MPa and 2.6 percent lateral deflection.

1. INTRODUCTION

Superior mechanical properties of natural bone are due to its two phase porous microstructure made up of organic and inorganic components[1]. Existing lower extremity orthotics consist of combination of single bioinertmaterial like polymers, ceramics and metal [2].The development of bamboo composite with bonelike mechanical properties requires a biomimetic approach using natural bone as a guide[3]. Natural bamboo also has two phase porous structure with vascular bundle of bamboo fiber and basal tissue that consist of parenchyma cells [4]. The fibre bundle of bamboo is densely packed near the outer wall of bamboo. The density of vascular bamboo fibers decreases radically inwards as the proportion of basal tissue increases[5]. External forces on tibia consist of 3 components in the direction of progression, vertical component and a sideways ground-to-foot force, all three perpendicular to each other [6].Study of human models suggest that bending is the primary component of long bone loading [7]. During walking and running tibia can bend in posterior and medial aspect [8]. Brittle matrix reinforced with bamboo sticks has been found to exhibit elastic behavior during flexural test therefore it can be used to make orthotic extremity [9].

The objective of this study is to achieve structural performance of tibial member in prosthetics similar to natural leg. This includes calculation of size of composite shaft equivalent to a tibia, limiting lateral deflection of shaft to corresponding tibial deflection, finding volume fraction of fibres for maximum strength and Experimental verification of Flexural modulus of composite shaft.

2. METHODOLOGY

2.1 Size of Orthosis

In order to establish structural equivalence between isotropic epoxy matrix of composite and anisotropic tibia, a failure crieteria where bamboo reinforcement looses contact with epoxy matrix was used. The size of pure epoxy column that has same stress as that of tibia under normal gait loading condition was considered fit for the application. CAD model of shaft was made in Ansys Workbench with epoxy material properties applied to the column. Design points with shaft diameter corresponding to standard mould size were chosen to get von mises stress. A plot of column size against von mises stress when subjected to gait load is shown in figure 1. Design point with diameter 38mm exhibited stress close to the stress value in case of natural tibia on normal gait load [10].

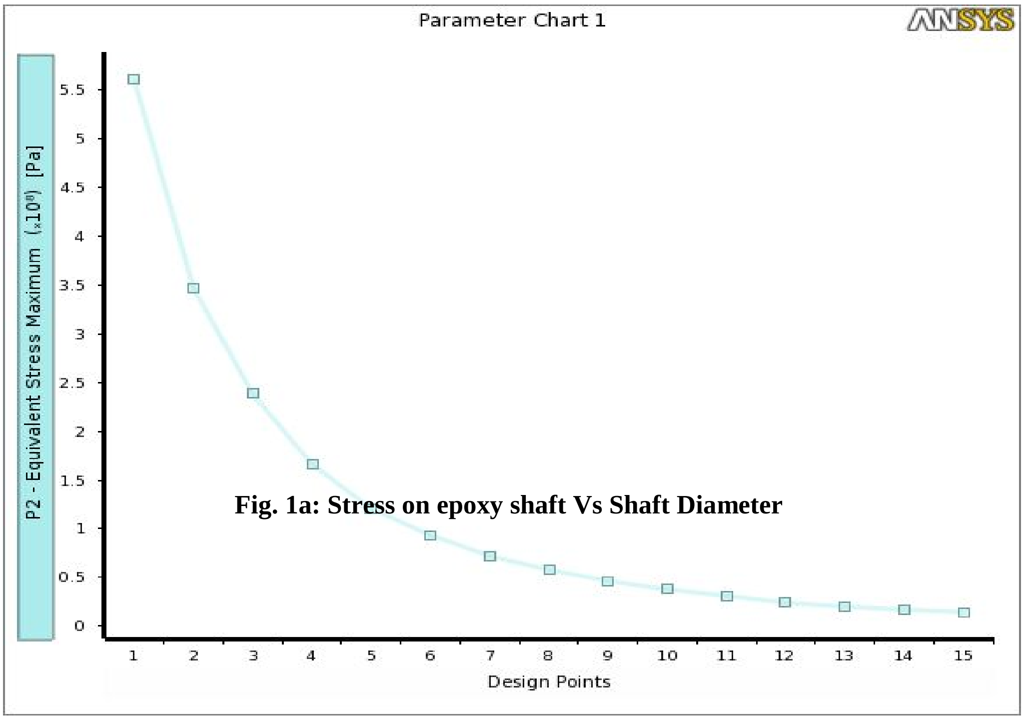

Fig. 1a: Stress on epoxy shaft Vs Shaft Diameter

2.2 Volume Fraction of Orthosis

With column size fixed the fraction of reinforcement to maximize column strength was found out by considering iso-strain condition between bamboo sticks and epoxy matrix .Locally available bamboo stick samples were tested to find elastic modulus. Assuming the length of reinforcement same as that of the composite specimen, the area ratio was made equal to volume ratio. The ratio (k) of elastic modulus of reinforcement to that of matrix was fixed.

The relation for effective stress on weaker matrix (σ_m) in a composite column is given by Equation 1.Where Pc is the load on composite column, A is the gross area of column and A_r is the area of Reinforcement.

$$\sigma_m = \frac{P_c}{A+(k-1)A_r} \qquad (1)$$

Equation 1 was used as an objective function to be minimized. According to evolutionary theory any biological aspect of human body like tibial diameter and strength is driven by natural selection and random genetic drift [11]. To incorporate anthropomorphic character in orthosis, governing stress equation of bamboo composite shaft was chosen to be solved by genetic algorithm. This algorithm begins by creating a random population of initial values or data points of X1 and X2 in this case. Equation 1 is called as fitness function which serves as the merit criteria for these values. Based on the value of fitness function at different data points, a new generation of data points is generated. Data points in every new generation is subjected to constraints based on the physical size limitation of shaft and non-negative area of both matrix and reinforcement.

2.3 Size of Reinforcement in Orthosis

The size of reinforcement was found by calculation of stress on a quarter column model. With reinforcement size and radial distance from the centre as design data points, stress on composite shaft corresponding to the tibial load of standard gait was found. Plot of Variation in the design parameters with stress in figure 2 shows that the stick reinforcement size of 1mmx1mm was found to be inducing least stress on the epoxy matrix.

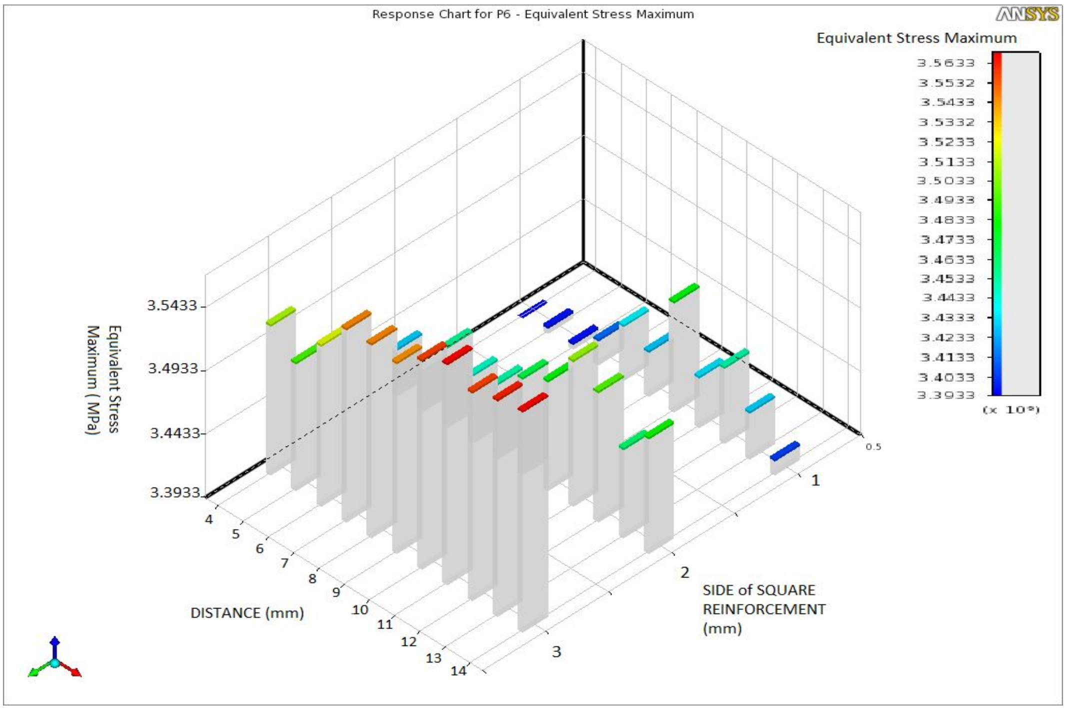

Fig. 2: Geometry of Force Analysis

It was found from the sensitivities chart that the strength of the column was affected significantly by the size of reinforcement. Tibial orthosis is subjected to bending stress hence cross-section of reinforcement sticks was chosen to be square. Linear Co-relation in figure 3 exhibited least stress in quarter column corresponding to reinforcement size 1mmX1mm.

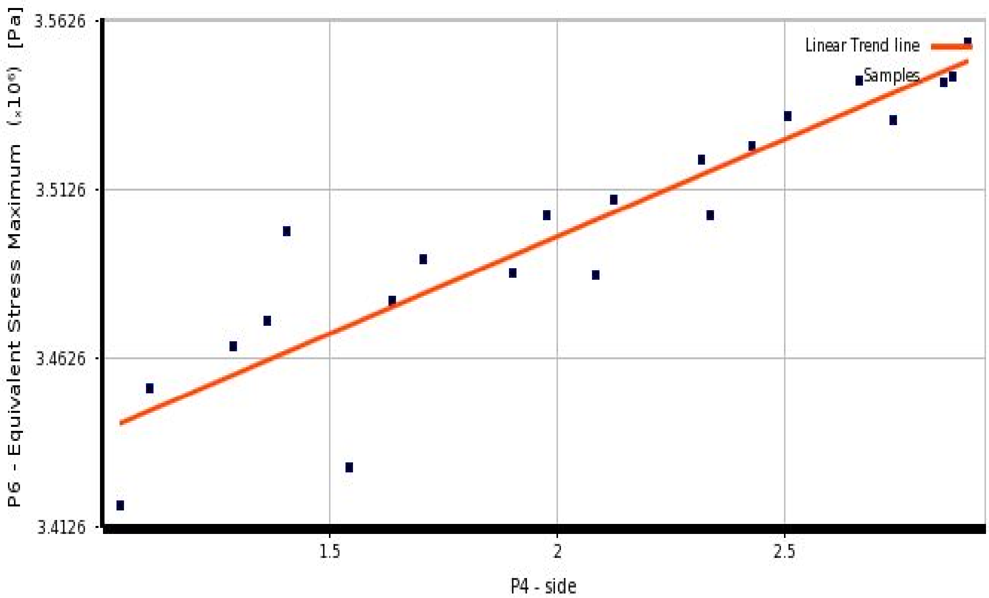

Fig. 3: Linear regression Co-relation between reinforcement size and column stress

3. ANALYSIS AND RESULTS

Reinforcement of square shape with side 1mm cut from the top, mid and base section of the bamboo and was subjected to tensile load to determine elastic modulus and tensile strength of bamboo stick. Stress-Strain plot of the samples is shown in figure 4 where Sample A, B and C are obtained from the top, middle and base portion of the bamboo plant. It was found that the strength of sticks obtained from the top of bamboo had highest tensile strength. Slope of Stress-Strain graph was used to calculate elastic modulus of bamboo reinforcement. Elastic modulus of Vascular fibre varies between 1 to 8 percent between top and mid section of bamboo [12]Elastic modulus of fibresin vascular bundle obtained from the middle part of bamboo was found to be 1% higher than that of the middle section fibres as shown in figure 4.Where slope of linear regression of stress-strain plot is the elastic modulus.

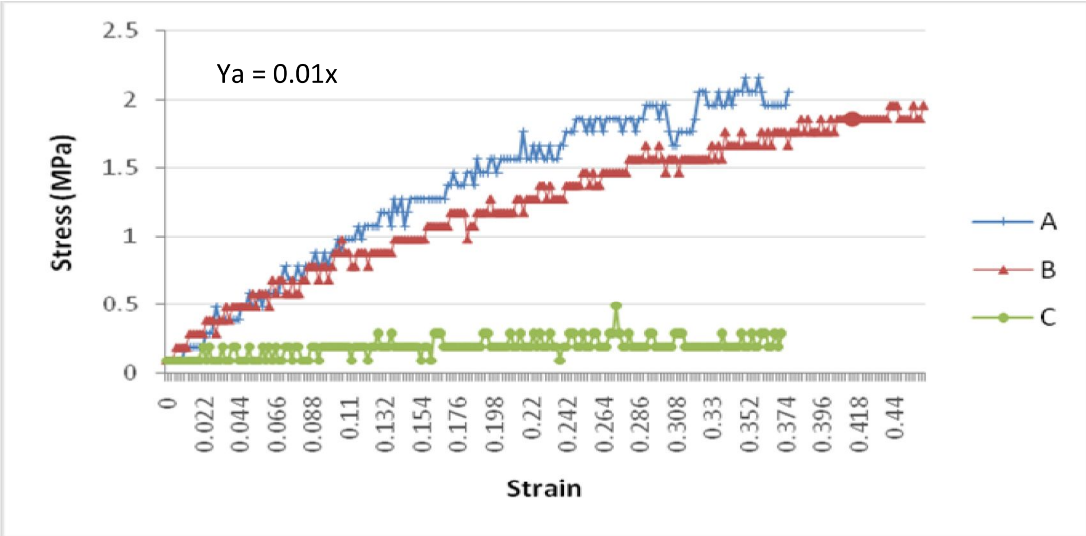

Fig. 4: Strees Vs Strain plot of Bamboo Specimen

3.1. Experimental Setup

Epoxy resin was poured into the mold and number of bamboo sticks were added such that the volume fraction of the composite remains constant for different reinforcement sizes. Composite specimen were subjected to bend load under 3 point bend test. Speed of loading was set to 10 mm/min. Columns of diameter 38mm and 51% reinforcement by volume. Specimens of length 150 mm were cut and subjected to bending load with a span of 100mm. Specimens A,B and C corresponding to reinforcement sizes of side 1mm, 2mm and 3mm respectively were subjected to 3 point bend test. Specimen was loaded till the appearance of initial visible crack in the epoxy matrix or there was a continuous fall in the force required deflect the specimen whichever was earlier. It was found that composite specimen reinforced with 1 mm size bamboo stick took highest load of 16865.5 N before failure while Specimen B having reinforcement size of 2mm and C with 3mm bamboo reinforcement had failure load equal to 14660N and 11142 N respectively.

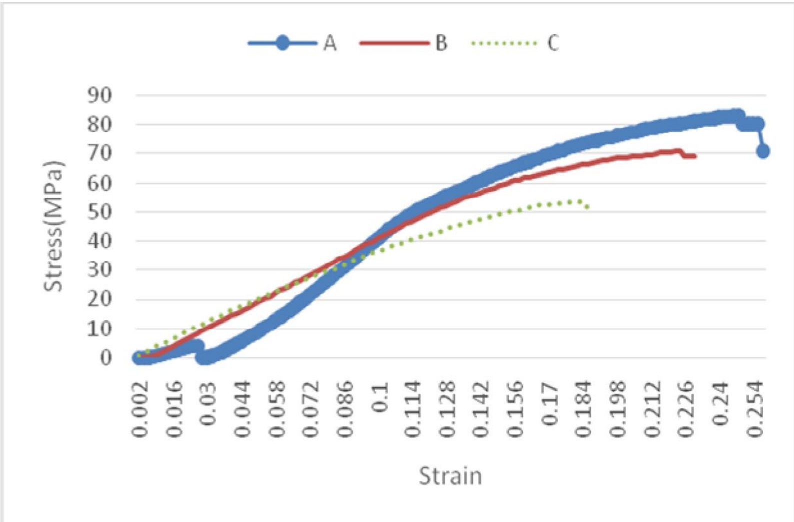

Fig. 5: Test Setup **Fig. 6: Stress Vs Strain Plot for Test Samples**

3.2. Test Results

Three Point bend test for all three samples with reinforcement size of 1mm, 2mm and 3mm gave flexural strength of the composite. To validate the effect of size of reinforcements shown in figure 5. Composite column volume fraction for which the strength was maximum was already determined by solution of stress equation by genetic algorithm. Lateral deflection of composite column had to be measured for comparison of composite extremity with the lateral deflection of tibia when subjected to gait load. Lateral deflection was measured in the direction of motion of UTM probe and percentage deflection was found out with reference to the length of sample

Table 1: Peak torque values from multimode simulation and experiment

Composite Sample	Reinforcement Size	Force (n)	Flexural Strength (Mpa)	Percent Lateral Deflection
Sample A	1mm X 1mm	16865.5	83.39	2.6 %
Sample B	2mm X 2mm	14660	70.76	1.6 %
Sample C	3mm X 3mm	11142	53.784	1 %

4. CONCLUSION

The results indicate that lateral deflection of composite column was within 3 for equvivalent to combined loading on tibia during walking and was less than 6 percent for maximum tibial load during running[10]. Robustness of bamboo fibrere inforced composite orthosis is established by the factor of safety of 5 with maximum strength of composite shaft being 83.93 MPa. Simulation co-relation and Experimental results show increase in strength of composite orthosis with decrease in the size of reinforcement. Tensile tests conducted on bamboo stick fibres revealed that elastic modulus of fibres in vascular bundle obtained from the top part of bamboo was found to be 1% higher than that of the middle section fibres. Owing to the similarities in the microstructure between bamboo and bone, a composite column can be used as an orthotic extremity with the use of bio mimetics, genetic algorithm and structural equivalence principles. Such an orthosis in artificial leg can be robust enough for loading conditions of both standard human gait and heavy physical activity levels.

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