

## Technical Note

### Mechanical Properties of Bamboo, a Natural Composite

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#### SUMMARY

*Experimentally measured values of the mechanical properties of bamboo, namely, the tensile strength, the Young's modulus, the compressive strength and the interlaminar shear are presented in this paper. The values compare very favourably on a weight to weight basis with conventional materials such as mild steel and glass reinforced plastics. As the absolute values of modulus and strength of bamboo are higher than that of plastics, it has considerable potential as a reinforcement for these materials.*

#### INTRODUCTION

Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries. It consists of cellulose fibres—nature's prime building material for living matter—imbedded in a lignin matrix. Cellulose fibres are aligned along the length of the bamboo providing maximum tensile, flexural strength and rigidity in that direction. A section of bamboo clearly shows that the fibre density is not uniform; it is higher at the outer periphery thus optimising the flexural properties.

Bamboo is commonly used, in those countries where it occurs, for structural applications such as building huts, scaffoldings, containers, etc. However, a systematic study evaluating the properties of bamboo as a composite material, though highly desirable, has not come to the notice of the authors.

#### EXPERIMENTAL

The present investigation has been carried out on specimens made from a dry bamboo having an outer diameter of about 55 mm and a shell thickness of 8 mm. The following properties are determined, namely:

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- (a) tensile strength and modulus in the direction of the fibres (along the length),
- (b) tensile strength across the length,
- (c) compressive strength along the length, and
- (d) interlaminar shear along the length.

The tensile strength and modulus are determined by using specimens about 200 mm long and having a  $6 \times 12$  mm rectangular section in the gauge region. The specimens are cut from the bamboo shell and the curved surfaces are filed flat for proper grip in the Universal Testing Machine. The strain is measured by a mechanical extensometer mounted on the specimen. The tensile strength across the fibre direction is measured by using specimens cut in the form of rings from the bamboo shell having about 55 mm o.d., 8 mm thickness and 20 mm width. The National Ordnance Laboratories test (NOL ring test) is conducted on these specimens. A special grip, matching with a 40 mm i.d., which consists of two semi-circular pieces inserted inside the specimen, is prepared to carry out the tests—uniform tension is applied over a small region of the specimen by pulling these pieces apart. However, as the inner surface of the bamboo is not perfectly circular, the surfaces of the semi-circular inserts and the bamboo do not match properly and hence tend to give a lower value of breaking strength.

The crushing strength is determined by using short rectangular specimens of nominal dimensions  $25 \times 13.7 \times 5$  mm (ASTM.D-659). The load is applied on the  $13.7 \times 5$  mm face. For interlaminar shear, a specimen of overall length 150 mm and  $10 \times 6$  mm section is used. Grooves across the width on the opposite faces are cut to obtain interlaminar shear when a tensile load is applied at the ends.<sup>1</sup>

## RESULTS

Tables 1 and 2 present results obtained for bamboo together with the typical values for mild steel, polyester resin and glass reinforced plastics. The values for two types

TABLE 1  
MECHANICAL PROPERTIES OF BAMBOO AND OTHER MATERIALS

<i>Material</i>	<i>Density gm/cm<sup>3</sup></i>	<i>Tensile strength along fibres</i>	<i>Tensile strength across fibres</i>	<i>Young's modulus along fibres</i>	<i>Inter- laminar shear</i>	<i>Compressive strength along fibres</i>
Mild steel	7.9	400	—	200000	—	—
Polyester resin (typical)	1.1	40	—	4000	—	100
GRP with WR and CSM	1.45	150	—	7200	15.0	130
Unidirectional GRP	1.8	450	25	41300	10.0	300
Bamboo	0.9	193	8.1	20600	9.2	68.4

Note: All values are in N/mm<sup>2</sup>.

of glass reinforced plastics are presented; the third line represents typical values for a glass reinforced plastic (GRP) laminate made from alternate layers of 450 gm/m<sup>2</sup> chopped strand mat (CSM) and 610 gm/m<sup>2</sup> of woven rovings (WR). The final properties of such a laminate are almost isotropic. The fourth line represents typical values for unidirectional glass reinforced plastic laminate containing 65 % glass by weight.

In Table 2, the same values are expressed in reduced form, as specific strength and modulus, i.e. in terms of the strength and modulus divided by the density.

TABLE 2  
COMPARATIVE VALUES OF SPECIFIC STRENGTH AND MODULUS

<i>Material</i>	<i>Specific modulus</i>	<i>Specific tensile strength</i>	<i>Specific compressive strength</i>
Mild steel	25316	50.6	—
Polyester resin	3636	36.4	90.9
GRP with WR and CSM	4965	103.4	89.1
Unidirectional GRP	22944	250.0	166.7
Bamboo	22889	214.4	75.96

Note: All values are in km<sup>2</sup>/s<sup>2</sup>.

#### DISCUSSION AND CONCLUSIONS

The values in Tables 1 and 2 clearly reveal the major advantages and disadvantages of bamboo as a structural material. Its absolute properties are below that of mild steel and GRP having unidirectional reinforcement, though they are much better than that of a typical thermosetting resin and also the hand lay-up GRP made from CSM and WR.

The specific strength of bamboo is much higher than that of other materials listed in the table except unidirectional GRP. The specific moduli of bamboo, mild steel and unidirectional GRP are comparable. The specific properties provide an insight into comparative strength and stiffness on a weight basis, particularly under unidirectional loads; in fact, a lighter material is more advantageously placed on a weight basis when the components are subjected to flexure.

A comparison of the properties of bamboo given in Table 1 with the properties of other woods given in Table 38 of Roark and Young<sup>2</sup> indicates that the bamboo is stiffer and stronger than all the types of woods mentioned in that table.

A perusal of the values in Table 1 indicates that in addition to its traditional uses in structural applications, bamboo can be used effectively for reinforcing plastics because its modulus and strength are both higher than the unreinforced plastics and its elongation at rupture is about 1 %, which is satisfactory for the cheaper varieties of thermosetting resins.

Thus, considering the mechanical properties of bamboo together with its low cost, it can be said that bamboo has tremendous potential as a structural material. The

important factor against its widespread use is its susceptibility to environmental degradation, i.e. deterioration in mechanical properties due to humidity, light, temperature and bacteriological effects. The effect of these parameters can perhaps be reduced by suitable coating or treatment. An investigation into environmental degradation of bamboo would be desirable to properly assess its utility in long term use.

## REFERENCES

1. BS 4994: 1973, 'Specifications for Vessels and Tanks in Reinforced Plastics', British Standards Institute, p. 76.
2. R. J. ROARK and W. C. YOUNG, *Formulas for Stress and Strain*, McGraw Hill Kogakusha Ltd, 1975, p. 608.

S. C. LAKKAD and  
J. M. PATEL†  
*Department of Aeronautical Engineering,  
Indian Institute of  
Technology, Bombay  
400076 (India)*

† Present address: Department of Civil Engineering, S.P. Regional Engineering College, Surat, India.