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Two Stage Procedure for Assessment of In Situ Compressive Strength of Bamboo Reinforced Beams Using Non Destructive Tests

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Abstract
'Bamboo' is used in place of structural as well as reinforcing steel because of its good physical and mechanical properties, shrinkage and average density. It can be considered as well established building material for the developing countries such as India, Africa and South America etc. although the implementation techniques, suitable connection techniques are need to be improving. In this study in first stage singly bamboo reinforced beams and cubes of conventional mix grade from M 25 to M 40 were casted and two different Non Destructive Test methods, Schmit Hammer and Ultasonic Pulse Velocity as well as destructive test using compression testing machine were carried out in second stage Statistical Regression technique applied on the results obtained from two different Non Destructive Test methods, Schmit Rebound Hammer (RN) and Ultasonic Pulse Velocity (U) and destructive test results in order to derive correlation of compressive strength (y) of bamboo reinforced concrete.

Keywords: *Bamboo Reinforced; Destructive Testing; Rebound Hammer; Statistical Regression; UPV;*

1. Introduction

1.1. Bamboo

In the recent year study on sustainable material has been increase so as use of locally available for economical purpose. The researchers are led to incline towards the sustainable construction and its benefits. The bamboo is well known as sustainable application, use as renewable resource and high strength alternative product of timber and occasionally called as "Green Steel". One of oldest sustainable natural giant grass is bamboo, belongs to Bambusoideae. Bamboo and its more than 100 species in ample amount are available in India. Wood resources are exhausted because of deforestation; bamboo is renewable material and good substitute of wood. Bamboo is fast growing plant takes 3 to 5 years to mature with the help of very less water, absorbed much carbon di oxide as compare to other trees and also prevents soil erosion. Environment is also affected by CO_2 content which proportionally increases with use of steel and concrete. Construction industry is also responsible for increasing CO_2. Gradually production of concrete and steel decorates the Environment. Approximately two tons carbon is releases over use of one ton steel (Ghavami, k. 2005). In India, Bamboo has been recognized as well established building material but its poor implementation on building is being very drastic most of time. Therefore there is need for planning, design, specifications in the favor of building development. Superior guidelines and framework should be needed for building bamboo structure.

The recent studies worked on fire safety parameter (Gutierrez, G.M. 2020) presented theory about fire assessment analysis of bamboo reinforced structure and also discussed the thermal performance and mechanical behavior of bamboo at elevated temperature with the help of mathematical model. The main aim was research to design fire safe bamboo structure.

1.2. NonDestructive Test (NDT)

Nondestructive technique is the key to monitoring y of structural concrete used in construction and rehabilitation works and also for conventional and nonconventional concrete such as bamboo reinforced

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concrete, self-compacting, fiber reinforced concrete, high performance concrete etc. using indirect methods due to their simplicity and quicker execution. The NDT techniques are relatively quick, less expensive, and easy to use for

- Testing a number of points and location.
- Assessing the structure for various distressed conditions.
- Assessing damage due to fire, chemical attack, impact, age etc.
- Detecting cracks, voids, fracture, weak location and honeycombs.
- Detecting the actual condition of reinforcement.

The application of NDT is to identify damage in composite material during material processing, fabrication of components and also in service activities among which cracks, porosity, member dimension, location of cracking, presence of voids and honeycombing; reinforcement location and size; delamination and debonding; corrosion activity of reinforcement, extent of damage due to freezing thawing, fire or chemical exposure which are commonly detected.

2. Review of Literature

In 1914 Chow, H.K. at MIT discussed the design steps of bamboo reinforced beam and experiments were conducted for material testing of [1] bamboo such as split tensile test, column test, specific gravity test etc. [2] furthermore studies on bamboo bars were carried out in Germany by (Dutta 1936), in Italy by (De simone 1939), (in U.S. Glenn 1950); (Smith and Saucier 1964). U.S war production board finance Glenn's research on bamboo reinforced concrete described the principal use of bamboo canes and splints in [3] concrete construction; emphasizing the issues of deflection, ductility, bounding, ultimate load capacity. Further studies were carried out to calculate ultimate strength, bound strength and tensile strength and modulus of elasticity of bamboo. Initially Brink and Rush in 1966 developed the design of bamboo [4] reinforced concrete by using allowable stress approach compared to steel reinforced concrete developed by ACI 318. The highlighted hybrid approach in which bamboo (Arundinaria tecta) reinforced member was design as [5] unreinforced concrete section with maximum tensile stress of $0.67\sqrt{f_{ck}}$. Geymayer, H.G. and Cox, F.B. (1970) proposed benchmark for the design of bamboo reinforced flexure member. The strength of [6] unreinforced flexure member used can be increased by adding 3 to 5% of longitudinal bamboo reinforcement. Youssef (1976); Indra (1982); Subrahmanyam (1984); Khare (2005); Rahman et al. (2011) proposed their researches on bamboo reinforced member by using design methodology of [7] Geymayer and Cox (1970). The experimental studies conducted on durability of bamboo, water absorption, bounding strength and its treatment [8] (behavior of untreated bamboo as reinforced concrete in fresh concrete, during curing of concrete and at stage of cured concrete, the shear strength of half bamboo was found 10.89 MPa with standard deviation of 2.56 MPa and according to Brazilian norms study concluded that 3% of treated bamboo reinforcement would be used as the conventional steel in normal concrete [10]. (Ghavami, k. 2005). Shear and flexural strength of concrete beam specimen reinforced with bamboo strips and compared the results with conventional and plain concrete samples, 3.8% longitudinal bamboo reinforcement showed better performance than plain cement concrete beams (Mali, P.R. and Dutta, D. 2020). [11] 16mm and 20mm bamboo splints were treated with tor (coating of bitumen and sand) to increase the bond strength (Farhana Narznin et al. 2015). [17] Thin coat of epoxy resin used to achieve good bonding (Ashwin, V. et al. 2015). The bond performance investigated by conducting pull out test of bamboo embedded in fly ash geo-polymer [18] concrete, modifications like corrugation in bamboo strip and bamboo strip wrapped with G.I. wire were used to improve bond strength than the plain bamboo (Awalluddin, D. et al. 2022). More research works are to be need to combined aspects of mechanical behavior, bamboo concrete bonding and its strength. Brink, F.E. and Rush, P.J. in 1966 proposed a technical report based on design and construction of bamboo reinforced member. Various researchers had compiled their experimental data to assist the selection and preparation of field bamboo structure.

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Six important design examples were discussed with design principal for more common structural members such as beam, column, [19] slabs and walls. Bamboo as reinforcing material used in casting, testing and provided design concepts about beam, slab and column construction (Ghavami, k. 2005). Comparative study had been conducted between conventional and unconventional concrete column with bamboo reinforcement. [20] Strength capacity and ductility criteria checked for short column with untreated surface of bamboo in the domain of concrete; [23] Beam members were also casted and tested for determination of bending, modulus of elasticity, deflection values and results showed 3.2% bamboo could use in place of 1.6% steel because it showed same behavior in strength and ductility (Leelatanon, S.; Srivaro, S.; Nirundorn, M. 2010). An experiment theory to improve shear capacity of bamboo reinforcement [24] by using steel stirrups and rattan cane stirrups as shear links (Mark, A.A. and Russell, O.A. 2011). Treated and untreated bamboo bars embedded in concrete and compared results with conventional reinforced concrete. The result data showed that bamboo tensile strength is approximate 20% higher than the 'y' so it can predict better results when used as beam with shear link rather than the column (Prem Kumar, V et al. 2014). [29] The implementation techniques and connection practice covered in the literature which improves mechanical properties of bamboo (Leake, G., Toole, K. et al.). Strength of cylindrical samples evaluated with bamboo reinforcement. Concrete mixes 1:1.5:3, 1:2:4 and 1:2.5:5 with bamboo bars showed strength 14.20, 13.45 and 12.44 respectively (Muhzuz, H.M.A.; Ahmed, M.; Karim, R. and Ahmed, R. 2011). Slab samples of self-compacting concrete embedded [32] with bamboo reinforcement i.e. use for sustainable rural construction. Comparison had been done between normal concrete with conventional reinforcement and bamboo reinforced with SCC mix and concluded that 3% of bamboo reinforcement ratio has maximum ultimate deformation capacity in case of slab, irrespective to concrete type (Mark, A.A. and Russell, O.A. 2018). A research was conducted on the use of bamboo as reinforcement in cement concrete matrices by replacing steel reinforcement (Wibowo, A., Wijatmiko I. and Nainggolan, C.R., 2017). A technical note presented by (Kaminski, S. et al. 2016b) this part discussed about bamboo preservation techniques, the causes of bamboo decay and its suitable remedies. In this series (Kaminski, S. et al. 2016) part: 3 also presented a technical note on limit state methods of strength designing, moisture content and moisture content correction factor. The technical note series published by (Kaminski, S. in 2018) discussed about characteristics of bamboo varieties, basic properties of bamboo used for structural consideration, behavior of bamboo during fire and earthquake. Research also confirms that all bamboo species have different characteristics, ultimate, allowable, design; factored strength and results do also affected by testing methodologies. As it is natural material therefore its physical and mechanical properties varies across the section well as along length. Due to absence of fibers in radial direction, making bamboo is weak in shear and on other hand man made steel is good in longitudinal shear, transverse tension and compression etc. additionally optimization is another issue whether it (bamboo) shape or mechanical properties, and it is not relatively easy to optimize bamboo without changing the its properties and nature. On other hand steel is easily optimize with its mechanical efficiency. Later on researcher were more specify as they were approaching for proper grade (Dutta, M. 2019) compared the results obtained from compressive and flexural test of plain cement concrete (PCC), steel reinforced concrete and bamboo reinforced concrete for 40 MPa design mix according to IS 10262:2009 and concluded that bamboo showed reasonably good flexural reading in comparison of PCC. Experimental studies conducted on bamboo reinforced concrete of grade M30 to calculate its flexural strength. 30 cylindrical samples were prepared and tested for flexural strength. Results concluded that in comparison to plain concrete bamboo showed better resistibility to flexural strength as it able to withstand with bending stresses (Sutharsan, R. et al. 2020). Advantage, disadvantage and Applications were discussed by (Srimathi, S. et al 2016). Bamboo has served for much type of structures due to its simple

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functioning and physical characteristics. Its combination with the other type of material is enhancing its importance. An application of bamboo as low cost housing had announced in Latin America (Kaminski, S. 2018). Hu, Y; Chen, S; Xie, C; Zhong, W; Yin, H; Luo, Z; Luo, B; Liang, B; Huang, J. (2022) gave experimental analysis on bamboo grid used as geo-grid in highway construction. The comparable results obtained for plain, singly and double sections of bamboo reinforced cylindrical concrete specimens. Singly and doubly sections of bamboo reinforced performed better than plain section. (Ramaswamy, S.N.; Mathew, A. 2019). (Mark, A.A. and Russell, O.A. 2018) used trial mix of 1:2.7:1.8 with super plasticizer 1.2% by weight of cement for construction of bamboo reinforced self-compacted one way slab.

3. Experimental Program and Data Extraction

Selection of bamboo culms are under consideration of some factors such as choose the culm in well-seasoned brown color, straight longest large diameter (50-200 mm) of culm is suitable, lower starch content so that to resist fungi and insect attack (FPL, wood handbook 2010; Wood Protection Association 2012). Sizing should be done by either splitting large culm into approximate three fourth inch wide or use whole culm for diameter less than ¾ inch. Waterproofing is also required while using as reinforcement (FPL 2010; Wood Protection Association 2012). To established good bond between concrete and bamboo use thin coatings of asphalt emulsion, coal tar, paint, native latex and locally available emulsions (Ridout, B. 1999). Ordinary mix design that could be with steel reinforcement would prefer. Low slump with allowable workability should be considered. Material used in this study was rounded crushed aggregate of sizes 10mm and 20mm normal aggregate from Kakani quarry Jodhpur Rajasthan. The cement used was ordinary Portland cement (OPC) of 43 grades confirming to IS 8112-1989 having specific gravity of 3.15. UPV readings are sensitive to water content. Decreasing exponential model is best fit to describe behavior of velocity with change of water content for conventional concrete (Gonzalez, M.R. and Caceres, R.B., 2003). Water reducing admixture is added to maintain the desirable w/c ratio. These admixtures fulfill the requirements of ASTM C494/ C494M. Recommended dosage (0.5-1% of cementitious material) has been used in this study. In general practice, the destructive testing is often not allowed in several structures. It requires more time due to laboratory testing, thus nondestructive testing results are converted to the 'y' based on correlation procedure of NDT apparatus. In this experimental program total 48 beams and 52 cubes from M25 to M40 mixes were casted. 'Y' in MPa (IS 516:1959), RN as per IS 516 (part 5 /sec 1, 2018) and U in Km/sec as per IS 516 (part 5 /sec 4, 2020) test were carried out to calculate strength variation at 28 days and developed correlation equations from the values obtained by destructive and non-destructive tests. Schmidt rebound hammer test was carried out for each beam and cube with an average of 10 readings on top, bottom and side face. Similarly average of three UPV readings in Km/sec (direct and semi direct) were taken.

Table 1 Descriptive Analysis for Bamboo Reinforced Specimen

Parameters	UPV (U)	Rebound Number(RN)	y
Mean	5.96	32.98	32.78
Standard Error	0.547	0.664	0.576
Median	4.43	33	35
Mode	4.28	34	35
Standard Deviation	4.62	5.59	4.86
Sample Variance	21.30	31.35	23.62
Kurtosis	3.73	-0.487	-0.763
Skewness	2.12	0.221	-0.257
Range	18.88	22	15
Minimum	2.15	22	25
Maximum	21.03	44	40

4. Results and Discussion

The predictive obtained from the above experimental work using statistical curve fitting method shown in

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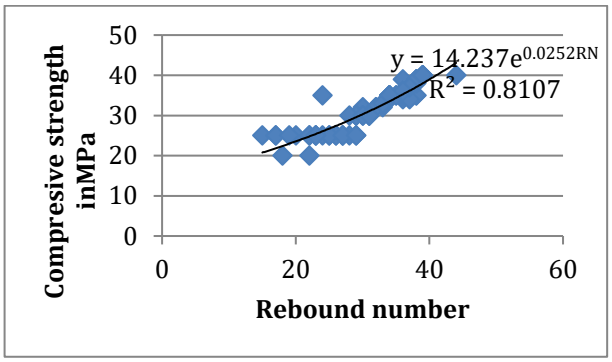
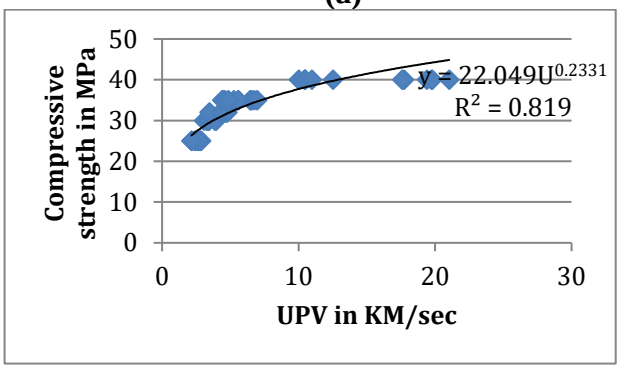
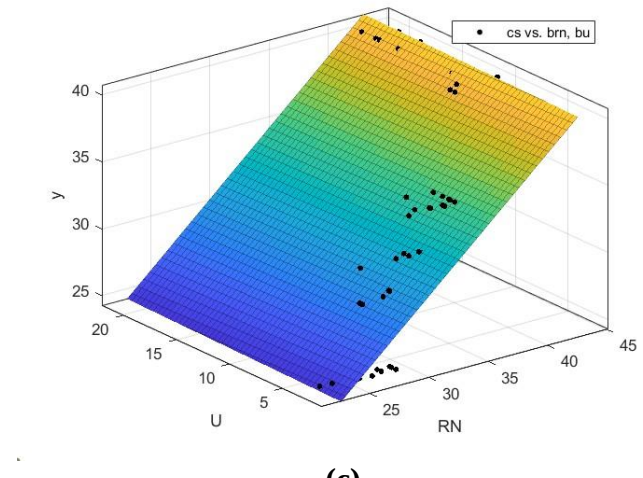
Figure 1 (a), (b), (c) below. The error computation shown in Table 2.



(a)



(b)



(c)

Figure 1 (a); (b); (c): Compressive Strength as Function of Inputs

The predictive correlation equations (1), (2) and (3) have been derived from the above experimental work using statistical curve fitting method.

$$y = 14.24e^{0.0252RN}, R^2 = 0.811 \quad (1)$$

$$y = 22.05\,U^{0.2331}, R^2 = 0.819 \quad (2)$$

$$y = 5.74 + 0.821RN - 0.013U, R^2 = 0.879 \quad (3)$$

Table 2 Error Computation

Equation	RMSE	SSE	R^2
1	1.83	231.39	0.811
2	2.395	390.69	0.819
3	1.718	200.76	0.879

Conclusion

Bamboo reinforced specimens are composite specimen of two materials i.e. concrete and bamboo. The densities of both materials are different; bamboo bar has density ranges from 5 to 7 KN/m^3 and concrete has 24 KN/m^3. However, the RN and Upv readings are affected by different densities but in this research it was observed that when RN and U readings are taken on a bamboo reinforced concrete beam, either it will strike at a location where there is reinforcement beneath or at a location, where there is no reinforcement beneath or only concrete location. The rebound number readings were observed for both locations. Hence bamboo reinforcement is not much influence the RN and U readings. Exponential and power correlation equations have been developed between in situ compressive strength and non-destructive testing values using only one non-destructive test technique for RN and UPV respectively. A combined linear equation (3) using RN and UPV values for bamboo reinforced concrete (Table 1). The correlation equations formed for compressive strengths 25-40 MPa give coefficient of determination (R^2) as 0.811 and 0.819 using only RN and only UPV values respectively. However R^2 for individual methods either RN or UPV shows good correlations but these methods have their different limitations, hence to predict more precise results it is advised to use combined RN and UPV methods. In this case, in situ compressive strength using combined RN and UPV values shows strongest correlation values is 0.879.

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