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Bamboo Ferrocrete

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Abstract: This study investigated the viability of employing bamboo as a potential reinforcement in ferrocrete structural elements, several tests on the "Nilgiri" bamboo species were carried out, and the outcomes of compressive and flexural tests were assessed using three different ferrocrete specimens which was used as a control beam. It was found that there was a clear correlation between the amount of reinforcement and the tested bamboo ferrocrete specimens' ability to support a given load. A mould or cube of 15 cm in size was tested for compressive strength. Ferrocrete's compressive strength is not particularly impressive; test findings indicate that specimen compressive strength declines as bamboo mesh reinforcing rises. Flexural tests were carried out using 100 mm x 100 mm x 500 mm beams. The variables used with test beams were specimens with no reinforcement (NM), specimens with steel mesh (FC), and specimens with bamboo mesh (BFC). Overall, test results showed that specimens with bamboo mesh reinforcement (3%) increased their load carrying capacity by 200 percent on average when compared to specimens without reinforcement and were nearly equals to the specimens with steel mesh reinforcement (1%).

Index Terms **- Ferrocrete (FC), Bamboo ferrocrete (BFC), bamboo mesh, Modulus of Rupture (MoR).**

I. Introduction

Small and medium-scale industries create opportunities for local employment as well as utilizing locally available resources. Hence, small, and medium industries play a significant role in the developing economy of India. They are also important for regional development and balanced development of the country in general.[1] The ferrocrete industry is a significant option for developing small industries in rural areas. It requires minimal capital investment and can provide employment opportunities to local communities. Different types of structures that can be built using ferrocrete, including garden benches, manhole covers, elements of houses, small water tanks, etc.

Steel and cement mortor are used to create ferrocrete, also known as ferrocement. Ferrocement or Ferrocrete is precast or cast-in-situ layered construction made of reinforced concrete in which thin steel wire grids are put in the cross-section rather than discretely positioned reinforcing bars, and cement mortar is used instead of concrete. The cement mortar used in ferrocrete is deposited over wire meshes. Ferrocrete is formed of a composite material that is filled with cement mortar with higher strength, tightly twisted around skeleton steel, and made of a steel wire mesh.[10]

In this research work, instead of steel reinforcement, treated bamboo was used as a reinforcing material in ferrocrete members to check the suitability of bamboo in ferrocrete structures.

II. Materials

Cement mortar, skeleton steel, and mesh reinforcement are the main components needed for ferrocement structures. The reinforcing mesh and mortar mix are the main components of typical ferrocement.

The key factors affecting the qualities of the cement mortar mix are the chemical composition of the cement, the kind of aggregate, the ratio of aggregate to cement, and the ratio of water to cement. Natural aggregate used in ferrocrete construction must meet the criteria outlined in IS 383 (Specification for Coarse & Fine Aggregate from natural sources for concrete). Water was discovered to be appropriate for both curing and mixing. Water utilized must adhere to the standards outlined in IS 456.

2.1. Proportioning of Matrix & Guidelines

The proportion of cement to sand in mortar mixtures used in ferrocrete works ranges from 1:1.50 to 1:4, resulting in a high cement requirement but produces greater compressive strength mixture.[9][17] The water-cement ratio is another key aspect in the formulation of cement mortar and concrete. It is advised to maintain the water-to-cement weight ratio between 0.35 and 0.5 consequently. Trial mixes should be taken in order to produce mortars that are durable, dense, and of a consistency that allows them to easily passes through the mesh layers.

2.2. Steel Reinforcement and Mesh

Following are the types of Steel Reinforcement basically used in Ferrocrete structures;

1. Skeletal Steel
2. Welded Mesh
3. Woven Mesh

2.3. Bamboo Reinforcement and Mesh

The three-year-old, brown-coloured bamboo culms used for this project work are free of deterioration, fungus growth, or holes caused by white ants. The selected bamboos were chopped into the required size and form after being thoroughly seasoned in the air about more than three months. The bamboo strips with slacked lime coating are approximately 5 mm in diameter and 500 mm in length, as expressed in Figure No.1. In the current effort, "Nilgiri" (local name) species bamboo was utilized for ferrocrete reinforcement.

Similar to wire mesh, bamboo is likewise prepared, but for attaching the bamboo strips at intersections, we have chosen synthetic resin adhesive rather than welding. For the determination of compression strength as well as flexural strength, testing is done in this work, we had to create bamboo mesh with openings of 20 mm x 20 mm and 25 mm x 25 mm in both the longitudinal and transverse directions, respectively. Figure No. 01 represents the bamboo reinforcement mesh used in both the compressive strength test and the flexural test.

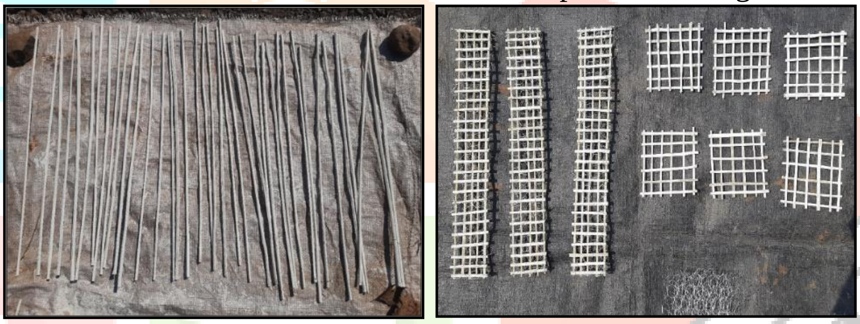

Figure No. 1: Bamboo strips and Bamboo mesh

III. Experimental Work And Discussion

Directions for the tests procedure that become recommended to determine the properties of the materials used in ferrocrete are provided in this section. Moreover, tests on ferrocrete members are covered.

3.1. Testing of Materials

Testing on basic materials is required because bamboo reinforced ferrocrete has been before used. To ensure the quality level of building work, testing is crucial. Systematic testing of raw materials, freshly-poured concrete, and hardened concrete must be a part of any concrete quality control programme if you want to increase the material's efficiency and improve the strength and longevity of the final product.

3.1.2. Physical & Mechanical properties of bamboo

The bamboo species employed in the current study, known locally as "Nilgiri," is "Dendrocalamus stocksii". The mechanical and physical characteristics that were experimentally measured and are shown in Table No. 1.

Table No. 1: Physical & Mechanical properties of bamboo

Sr. No.	Property of Bamboo	Value
1	Moisture content	33.00 %
2	Water absorption	12.62 %
3	Compressive strength	51.03 MPa
4	Tensile strength	107.30 MPa

3.1.2. Properties of mortor mix

The determination of the properties of cement mortor mix is done using the guidelines provided by Indian standards. The test results tabulated in Table No. 2.

Table No. 2: Properties of cement mortor mix

Sr. No.	Property of material	Value
1	Mix Proportion (cement: sand)	1:3
2	Water-Cement Ratio (W/C)	0.45
3	Compressive Strength of Mortor	
	7 days	28.72 MPa
	28 days	34.35 MPa
4	Density of Mortor	24.5 kN/m^3

3.2. Testing of Ferrocrete

The tests conducted to evaluate the properties of the ferrocrete structures are explained in this section. The present investigation consists of the following tests:

- Flexural strength of ferrocrete
- Compressive strength of ferrocrete

3.2.1. Flexural Strength of Ferrocrete

"IS 516 (1959): Method of Tests for Strength of Concrete" governs the process for creating and curing flexural strength test specimens of ferrocrete. In the present work, five types of specimens were prepared and studied for flexural strength. Type of specimen, its designation, number of meshes in each specimen & its percentage of reinforcement mentioned in Table No. 3. There were five different types of specimens prepared, each with three test samples. The specimens were loaded under two-point loading after testing to determine the flexural strength as a function of Modulus of Rupture (MoR), and the maximum load at failure was recorded.

Table No. 3: Modulus of Rupture of Ferrocrete and reinforcing mesh content

Sr. No	Specification of specimen	Designation	No. of layer of mesh	% Of reinforcement	Modulus of Rupture (MPa) 7 Days	Modulus of Rupture (MPa) 28 Days
1	Ferrocerete mortor only.	NM	0	0	3.94	6.17
2	Steel mesh in two layers.	FC	2	1	12.10	15.72
3	Bamboo mesh in single layer.	BFC-1	1	1	5.85	6.58
4	Bamboo mesh in two layers.	BFC-2	2	2	6.28	7.81
5	Bamboo mesh in three layers.	BFC-3	3	3	9.50	11.38

It is clear from the findings of the laboratory investigation that the flexural strength is influenced by the quantity of reinforcing mesh layers utilized in the ferrocrete specimens. Through varying the number of layers or either percentage of bamboo mesh from 2 to 3%, the specimens' ductility and flexibility to absorb energy are significantly enhanced. As a result, there are minimal cracks, and the fatigue and impact resistance are both improved (Figure No. 02). About 3 percent of specimens with bamboo reinforcement can generate flexural strengths that are nearly twice as strong as those without reinforcement. We can see that the flexural strength can be greater than three to four times that of an unreinforced specimen and will also be greater than that of a steel-reinforced ferrocrete specimen if we apply a chemical treatment to bamboo splints to prevent water absorption and any suitable method of increasing bond strength.

The experimental findings show that when the load increases, the tension face experiences its first cracks, which are due to mortar failure there. Even though, the load-bearing capability of the specimens enhanced as a result of the reinforcement meshes' extra stresses. As the stress increased, cracks started to spread close to the mortar layer. Moreover, cracks became wider and more numerous.

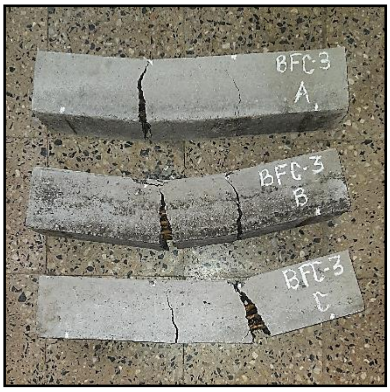

Figure No. 2: Crack pattern in BFC-3 (bamboo mesh) Specimen

Bending is the result of the interaction of factors that affect both tensile and compressive characteristics, including the strength properties of a mortar, the type, composition, and orientation of the mesh.[18] Lower percentages lead to insufficient strengths, while higher percentages lead to overloaded cross sections. The type of structure, the necessary level of strength, the energy absorption properties, and the economics all influence the appropriate percentage or spacing of bamboo reinforcement in ferrocrete.

3.2.2. Compressive strength of ferrocrete

"IS 516 (1959): Method of Tests for Strength of Concrete" governs the creation and curing of ferrocrete compressive strength test specimens. A cube of 15 cm dimension steel moulds was used for this test. There were five different kinds of specimens prepared and their compressive strength was examined in the current investigation. Table No. 4 lists the type of specimen, its designation, the number of meshes in each specimen and their arrangement, as well as the percentage of reinforcement.

Table No. 4: Compressive strength of Ferrocrete and reinforcing mesh content

Sr. No.	Specification of specimen	Designation	No. of layer of mesh	% Of reinforcement	Compressive Strength (MPa)	
					7 Days	28 Days
1	Ferrocerete mortor only.	NM	0	0	22.31	31.57
2	Steel mesh in two layers.	FC	2	1	20.34	26.44
3	Bamboo mesh in single layer.	BFC-0.5	1	0.5	18.80	23.08
4	Bamboo mesh in two layers.	BFC-1	2	1	17.84	22.70
5	Bamboo mesh in three layers.	BFC-1.5	3	1.5	17.90	17.89

As seen from Table No. 4, the compressive strength of ferrocrete specimens with reinforcing mesh (i.e., FC, BFC-0.5, BFC-1, & BFC-1.5) is less than that of the specimens without any reinforcing mesh (NM). Here we can easily see that the compressive strength of ferrocrete specimens diminishes as the number of reinforcing mesh (steel or bamboo) increases. This happens due to the Delamination [18], or splitting transverse tensile stresses and buckling of the mesh reinforcement under compression, as shown in Figure No. 03, appears to be the cause of the decrease in compressive strength. Increasing the number of layers or the percentage of bamboo or steel mesh significantly decreases the compression strength of the ferrocrete specimens.

Figure No. 3: Compression failure of Ferrocrete Specimen showing delamination

IV. Cost Comparison

Construction budget is a significant factor in construction for poor people in both rural and urban locations. Thus, efforts to develop a steel substitute must be affordable, practical, and long-lasting. The cost of any construction work or component is dependent on various major and minor factors.

4.1. Component of Estimates

Materials and labor are very important factors that are considered in the cost estimation process.

4.1.1. Labor

The hourly wage will be calculated using the maximum wage and the minimum number of hours and days worked each week as a conservative guide; Labor cost per hour is calculated by,

$$= \frac{\text{mothly wadges}}{\text{working day}'\ \ \text{s per month} \times \text{8 hrs per day}}$$

$$= \frac{10000}{26 \times 8} = 48.07$$

$$\approx Rs. 50\ per\ hour$$

4.1.2. Materials

For both types of members, i.e., ferrocrete with steel and ferrocrete with bamboo mesh, the price of ferrocrete mortor is the same. The type of reinforcing material utilized in the ferrocrete member, such as steel mesh or bamboo mesh, is anticipated to account for the difference in price of the beams. Whether the material is imported or locally produced also has an impact on price.

4.2. Cost Estimation for Mesh

The difference in price is due to the type of reinforcing material used, such as steel mesh or bamboo mesh. Other materials like cement and sand were kept constant for both specimens.

The capacity to bear a load of ferrocrete specimens with 3% bamboo mesh and 1% steel mesh is similar for the same mortar mix proportion, but BFC specimens require a greater percentage of reinforcing material than FC specimens. The cost of reinforcing material for both types of specimens is estimated in Table No. 5.

Table No. 5: Cost Estimation and Comparison of Steel mesh Vs bamboo mesh

Sr. No.	**Particulars**	**Steel Mesh**	**Bamboo Mesh**
1	Opening Size	25 x 25 mm	20 x 20 mm
2	Diameter of wire/strip	2.5 mm	5 mm
3	Number of mesh required	2	3
4	Cost per unit (sq.mtr)	Rs. 430	Rs. 250
	Total Cost	**Rs. 860**	**Rs. 750**

Through efficient planning and mechanized production processes, the cost-effective technology with bamboo has led to 15-30 percent savings over conventional costs. Particularly in tropical rural areas of India where bamboo can be grown and is readily available.

V. Conclusion

This study examined the potential of using bamboo as a reinforcement in ferrocrete structural elements. Tests were conducted on the "Nilgiri" bamboo species, and the outcomes of compressive and flexural tests were assessed using three different specimens. According to the test results, the following conclusions can be made:

- The failure loads varied with the percentage of the bamboo, providing a lower failure load for a lower percentage, i.e., 1%, and vice versa, according to the 28-day test results of flexural test specimens. As the percentage of bamboo increases, so does the member's ability to support loads.
- The compression strength of the ferrocrete specimens is greatly reduced by increasing the number of layers or the proportion of bamboo or steel mesh. The delamination appears to be the cause of the decreased compressive strength.
- It has been reported that, without proper preparation, premature grip failure drastically reduces strength. To prevent premature grip failure, the specimens with nodes at the ends were properly prepared by using appropriate gripping techniques.
- The surface treatment with slaked lime paint is eco-friendly, but it should not provide greater bonding between bamboo mesh and matrix. Bond-enhancing applications should be required if we need to strengthen the bonding between the matrix and the bamboo mesh in a special application.
- A critical component of ferrocrete is the proper proportioning of the constituents of cement mortor. The ferrocrete matrix should have a cement-fine aggregate ratio of 1:1.5 to 1:1.4 with a low w/c ratio (0.4 to 0.5), which provides greater strength.
- A cost analysis reveals that the cost of producing bamboo mesh is lower than that of producing steel mesh for the same load carrying capacity.
- Based on the few experiments that were performed, it was determined that bamboo might be an alternative to steel mesh reinforcement in ferrocrete applications. However, it is strongly advised to employ bamboo as reinforcement in ferrocrete for rural areas where bamboo is widely available and light-loaded structures are built.

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