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Strength Assessment of Jute Fiber Reinforced Concrete by Destructive and Non-destructive Test Methods

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Abstract

The search of a durable and low cost fiber reinforced cement concrete for construction works is an empirical challenge in developing countries. Economic scarcity have confined the use of carbon fibers in cementitious composites on a commercial level. Jute fiber has the potential to be used in reinforcement to surpass the inherent deficiencies in cementitious materials. In this research, jute fiber reinforced concrete is used to find out which test method is more reliable among destructive and non-destructive test methods. In recent years, one of the most challenging scientific method is intelligent defect detection. Non Destructive Testing (NDT) techniques are the most useful and the easiest methods due to their efficiency and low cost. The experimental process using Ultrasonic Pulse Velocity and Schmidt Rebound Hammer as Non-destructive Tests (NDT) are used in this paper to set up a correlation between the compressive strengths of compression tests and NDT values. These two tests have been used to find out the concrete quality by applying regression analysis models between compressive strength of jute fiber reinforced concrete and tests values. The relationship between compression strength of concrete collected from destructive test method and estimated results from NDT's records using regression analysis are compared together to assess their reliability of prediction of concrete strength. The test results show that destructive test methods are the most reliable way to find out the original strength of test specimens. After destructive test methods, the rebound number method is more efficient in predicting the strength of concrete under certain conditions. Schmidt Hammer rebound tests is recommended to estimate the strength of concrete to reduce the number of cores taken from the structures in practical cases.

Keywords:Jute fiber ; Destructive Test; Non-destructive Test; Regression Analysis; Reliable.

1. Introduction

Plain concrete has comparatively high compressive strength but owns a very low tensile strength, limited ductility and low resistance to cracking. Internal micro cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro cracks, eventually leading to the brittle fracture of the concrete (Raval and Kansagra 2017). It has been revealed that the addition of small closely spaced and uniformly distributed fibers to concrete would act as crack resistor and would significantly improve its static and dynamic properties. For these reasons, different kinds of fibers are used. i.e. natural fiber and synthetic fibers. Among natural fibers, jute is plentifully grown in Bangladesh, India, Indonesia, China and Thailand. Jute fiber being cheap, strong and durable, is a prospective reinforcing material for cement-based matrices (Mansur and Aziz 1982). The estimation of mechanical properties of concrete can be discovered by several methods; destructive and non-destructive tests. In this context, the destructive test procedure involves crushing of specimens which requires huge financial investment. Nondestructive methods like rebound hammer test and ultrasonic pulse velocity test do not damage specimens and allow to use the previously used specimens for further purposes. They are easy to use and economically advantageous. Additionally, their usage is quick. Test results can be collected immediately on the site and the possibility of concrete testing in structures is demanding in which the cores cannot be drilled and the use of less expensive equipment(Hobbs and Kebir 2007).

2. Methodology

Specimens are designed to find out the compressive strength of specimens. Finally, these values are compared with non-destructive test results.

2.1. Coarse Aggregate

12.5mm are used as CA. The required size of CA are collected from local shops. With the maximum size of CA 12.5mm having a specific gravity 2.86 and fineness modulus of 6.60 (ASTM 2015). The physical properties of CA are shown in Table-1.

Table 1: Physical properties of CA

Properties	Value
Specific gravity	2.76
Fineness modulus	6.60
Bulk density	Loose: 1450 kg/m^3
	Compact: 1700 kg/m^3
Moisture content	0.5%

2.2. Fine Aggregate

Sylhet sand is used as FA which has a specific gravity 2.22 and fineness modulus of 2.5. All values are determined by conducting sieve analysis in the Structural and Material Engineering Laboratory (SME Lab) at KUET (According to ASTM C128-84). The physical properties of FA are shown in Table-3.2

Table 2: Physical properties of FA

Properties	Value
Specific gravity	2.22
Fineness modulus	2.5
Bulk density	Loose: 1530 kg/m^3
	Compact: 1760 kg/m^3
Moisture content	0.5%

2.3. Cement

This research paper has investigated the mechanical properties of cementation materials to incorporate in sustainable development. It was also collected from Seven Rings Cement as OPC. The physical properties of Cement are shown in Table-3.

Table 3: Physical properties of OPC

Property	Results
Specific gravity	3.16
Normal consistency	26%
Initial	70 Minutes
Final	266 Minutes
Fineness	330 kg/m^2
Soundness	2.5mm

2.4. Jute Fiber

The basic necessities of any fiber for producing good quality fibrous concrete are high tensile strength, high elastic modulus, and good bond at the fiber-matrix interface, adequate geometric stability, chemical resistance and durability. Therefore, the use of this fibrous material may be a decent solution to the environmental problem for sustainable development. The water absorption, tensile strength and the percentage elongation are observed as follows:

Water absorption = 205.26%
Tensile strength = 262.6 MPa
% elongation = 1.16%

The jute is collected from the local market which is shown in Fig.1. It is abundantly grown in Bangladesh, one of the cheapest fibers and are about seven times lighter than steel fibers but with reasonably high tensile strength in the range of 250-300Mpa. Physical properties of jute are shown in Table-4.

Fig.1. Jute Fiber

Table 4: Typical Properties of Jute Fiber

Properties	Range of Values
Fiber Length	180-800 mm
Fiber Diameter	0.1-0.2 mm
Specific Gravity	1.02-1.04
Bulk Density	120-140 kg/m^3
Ultimate Tensile Strength	250-350 N/m^2
Modulus of Elasticity	26-32 KN/m^2
Elongation of Fracture	2-3 %
Water Absorption	25-40 %

2.4. Water

Water is a vital factor that plays an important role between the chemical reaction with cement & others binding materials. Potable water is used for required concrete mix preparations. Water-cement ratio is maintained 0.45 in this experiment.

2.5. Mix Design

Mix design consists of cement, water, fine aggregate, coarse aggregate & jute fiber. The mix design for this experiment is Cement: FA: CA = 1: 1.48: 2.7.

2.6. Specimen Preparation

After the mixing was done, the uniform mixing was placed in the molds by 3 layers. When the one-third of mixing layer was placed in the molds, compacting was employed by a temping steel compacting rod having 16mm cross-sectional diameter with length 600mm. After the finishing the temping of the top surface of the all molds that were left for 24hours to get dry. Each molds were marked with different marks for further identification of specimens. After the removal of all the molds, the specimens were again marked by a marker with a proper notation for the curing process. Then, the specimens were cured until 7days & 28days at room temperature 24±2^{0}C for testing purpose.

2.7. Destructive Test Method

2.7.1. Compressive Strength Test

The compression testing machine according to the standard ASTM-C39 was used for testing the cylindrical specimens that is shown in the Fig.2. 36 nos. of 200×100 mm cylinders were tested at 7and 28 days after casting. The capacity of the testing machine was 3000 KN. A loading rate of 0.15MPa/s was applied as given in ASTM C39.The cylinders were de-moulded. At 24 hr. and moist cured for the duration of their lifetime. Using UTM machine, uniaxial compressive load was applied. The failure load was measured and used to calculate the compressive strength. The procedures is referred to BS 1881: Part 115: 1986. Compression testing machine with the specimen is shown in the Fig.2.

Fig.2. Compression testing machine

2.8. Non-destructive Test Methods

2.8.1. Ultrasonic Pulse Velocity Test

The equipment consists of an electrical pulse generator, an amplifier, a pair of transducers and an electronic timing device for measuring the time interval between the initiation of a pulse generated at the transmitting transducer and its arrival at the receiving transducer .The pulse velocity test was dascertained using cylindrical specimens in accordance with the requirements of EN 12504-4. UPV machine is shown in the Fig.3.

Fig.3: Ultrasonic Pulse Velocity Machine

It is a non-destructive method generally used for checking the quality of the concrete elements (existence of voids, cracks, honey combs), but also for the assessment of its compressive strength. This method is mentioned in the international standards respectively ASTM C597:2009 and BS 1881-203:1986. This method provided direct values of compressive strength of concrete that is shown in the Fig.4.

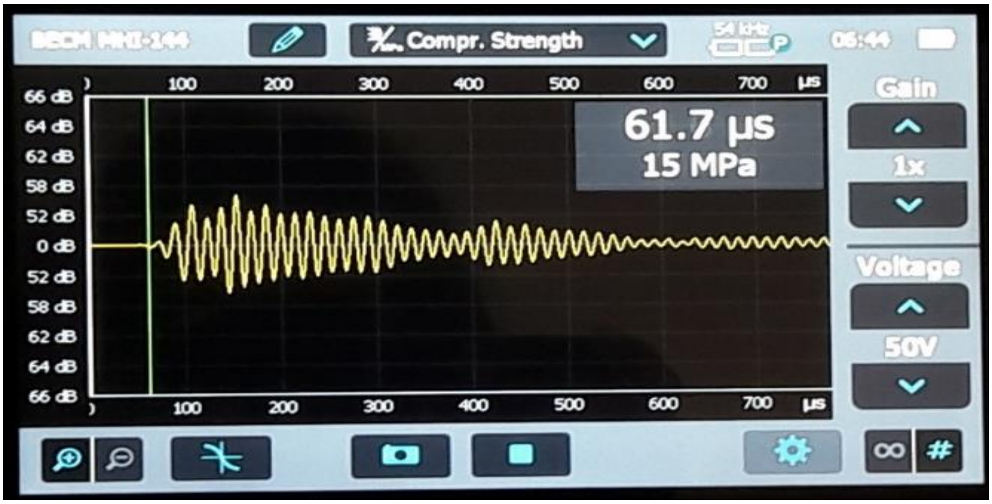


Fig.4. Compressive strength measurement by UPV machine

2.8.2. Rebound Hammer Test

The Schmidt rebound hammer is a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The position of the mass relative to the vertical, however, affects the rebound number due to the action of gravity on the mass in the hammer. The test procedure is shown in the Fig.5.

Fig.5: Rebound Hammer Test

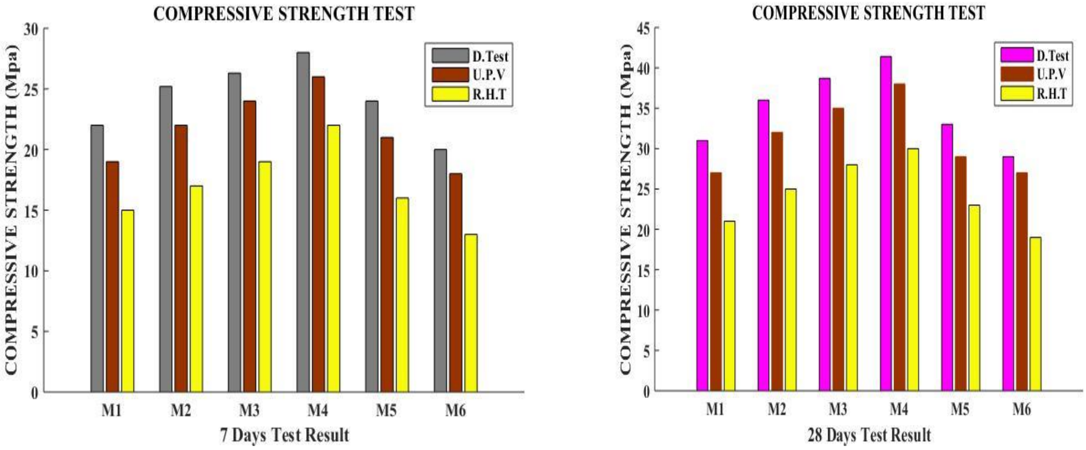
For testing Compressive strength with the help of rebound hammer, the specimen has to made smooth, clean, and dry. After setting up the entire necessary unit the test can be performed and the relative data can be collected. Concrete quality can be easily classified based on rebound number collected from the test. For this purpose, concrete quality based on rebound number has been classified in the Table 5.

Table 5: Concrete quality based on rebound number

Concrete Quality	Average Rebound Number (nos.)
Very good hard layer	More than 40
Good layer	30 to 40
Fair	20 to 30
Poor concrete	Less than 20

3. Results and Discussion

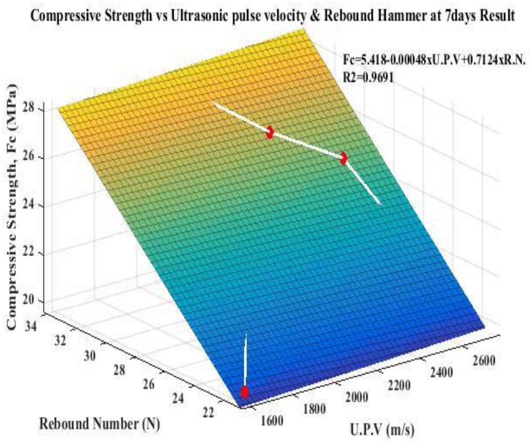
The Fig.6. shows the comparison between compressive strength collected from destructive test and the strength predicted by the ultrasonic pulse velocity and rebound hammer tests. The destructive test results are seemed to be more reliable.



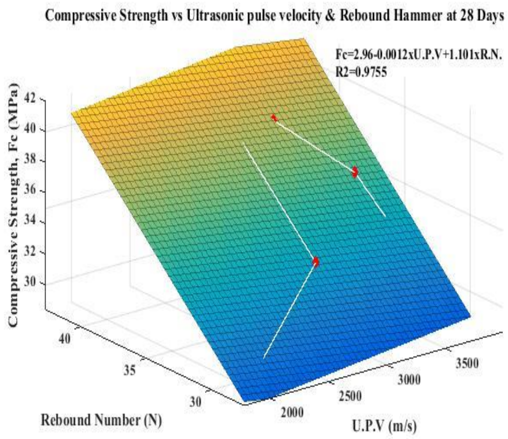
(a) (b)

Fig.6. Comparison of the Compressive Strength of specimens by Destructive Test, Ultrasonic Pulse Velocity Test and Rebound Hammer Test for (a) 7days and (b) 28days

At the ages of 7 and 28 days, the resistances obtained by the compression test were higher than those obtained by the ultrasonic pulse velocity test and rebound hammer test. This discrepancy might be caused by predicting the compressive strength from the surface impact of the concrete specimen. This is because the surface is not regular and the impact test is largely depended on the testing workability. Test results for hardened concrete show a reasonable correlation of compressive strength with the rebound hammer and Ultrasonic Pulse Velocity. The sensitivity of the pulse velocity test in measuring strength is affected by the concrete age, as the concrete matures, the sensitivity of the Ultrasonic Pulse Velocity to strength gain or achieved by the concrete increases. The rebound hammer shows less sensitivity as the concrete matures since it is a surface hardness test and for age above 7 days there is little or no gain in surface hardness. These variations of test results is due to low sound transmission and high signal noise. For better accuracy and practicability, multivariable linear regression analysis (MRA) is employed as a statistical approach shown in the Fig.7. MRA intends to simultaneously certify two or more independent influencing parameters. Based on a multiple regression analysis, this study suggests a dual variable regression equation for estimating the compressive strength of high strength concrete in practical applications.



(a)

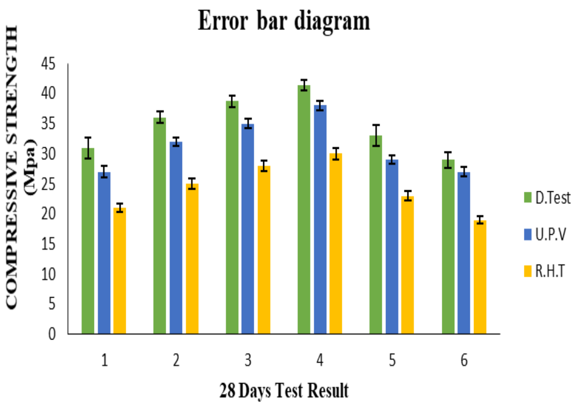


(b)

Fig.7. Relationship between Tested Compressive Strength of Concrete Cylinders and Predicted by Non-destructive Test for (a) 7 Days (b) 28days

In any case, a dual linear regression must have better prediction accuracy than a single linear regression approach. The R^2 value is found to be 96.91% for 7 days which indicates a significant correlation. Here, U.P.V and R.N. are independent variables and Fc is dependent on them. In case of 28 days, R^2 value is found to be 97.55%, which indicates that the more accuracy of the result. To determine whether these differences of compressive strength from destructive and non-destructive tests are statistically significant or not, error bar diagram is plotted in the Fig.8. for 7 and 28 days specimens respectively.

(a)



(b)

Fig.8. Error-bar Diagram for (a) 7 days (b) 28 days Test Result

The low standard deviations and low standard error means within the batches for all measured clearly shows that the process of destructive and non-destructive tests are reliable. In the Fig.9. , the standard error of the mean are plotted to get the error bar to adjust the uncertainty of the value of compressive strength. From the standard error mean values of destructive and non-destructive methods, the destructive test has shown has shown 34.7% and 51.6% less standard error mean than UPV and RHT methods respectively.

4. Conclusions

The destructive test method is proved to be more reliable in determining the compression strength of concrete specimens comparing with the non-destructive test methods. The difference between the values of strength obtained by destructive and non-destructive tests methods were not remained almost same at the age of both 7 and 28 days. The rebound hammer test can be used to assess the compressive strength of old concrete structures and but it is not recommended to use in case of newly constructed concrete structures. The Rebound hammer provides a quick, simple and cheap method of determining the strength of concrete. The results are affected by some factors such as smoothness of concrete surface, size of the structure or specimen, moisture condition of the concrete and the type of cement used. Schmidt Hammer rebound tests can be used to estimate the strength of concrete to reduce the number of cores taken from the structures. In case of ultrasonic pulse velocity test, the result is greatly affected by any kind of sound occurred near the test procedure. These tests have their own limitations and these limitations may result in errors. Applying proper correction factor is a must to get the reliable results. Despite all the corrections some of the errors are unavoidable. Combined method can abate these errors and give more reliable results.

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