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Experimental and Machine Learning Analysis of Concrete Performance Enhanced with Modified Jute Fiber Reinforcement: A Sustainable Approach

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Abstract:
In this experimental research, 36 concrete Cubes, cylinders and beams each were prepared, to study the performance of concrete reinforced with modified jute fiber, which focus on its mechanical properties and the predictive capabilities of machine learning (ML) models. Sodium hydroxide (NaOH) was used for the treatment of Jute fibers, then were uniformly cut to 20 mm lengths and added to M30-Concrete grade in 0%, 1%, 1.5%, and 2%. Material tests, for sieve analysis, specific gravity, and water absorption, were conducted on aggregates and jute fibers, with the concluding data showing high moisture absorption. Slump tests was done for the fresh concrete, demonstrated reduced workability as fiber content increases. Mechanical tests showed that, 1% jute fiber content revealed optimal improvements in compressive, flexural and split tensile strengths. The results were quantitatively analyzed, the hypothesis test was performed using ANOVA revealed that modified jute fibers do not significantly decrease compressive, flexural, or split tensile strengths, the p-values for all mechanical properties were greater than 0.05 level of significance, leading to the conclusion that the null hypotheses could not all be rejected. Machine learning models, encompassing multiple linear regression and Random Forest regression, were implemented to predict concrete properties based on fiber content and curing ages, with R-squared values of 0.948 for compressive strength and 0.879 for flexural strength. Nevertheless, the prediction of split tensile strength was less accurate. The results suggest that chemically modified jute fibers enhance tensile, flexural and compressive properties, and machine learning can effectively model these improvements.

Keywords: *Concrete Reinforcement, Modified Jute Fiber, Machine Learning, Sustainability, Concrete Samples, Random Forest, Multiple Linear Regression.*

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I. Study Background

Concrete is widely regarded as the most utilized construction material due to its durability, versatility, compressive strength and affordable cost. (Yang et al., 2011). While Plain concrete is a heterogeneous composite material, generally composed of Cement, Aggregates, and Water only, in the proportions specified by the requirements. (Yan, 2013). But the addition of discrete fibers to concrete increase tensile and impact, controls crack, wear and tear, fatigue and improves ductility, (Mohammadi et al., 2008). (Yazıcı et al., 2007). (Abdullah et al., 2022), stated that, Steel, carbon, plastics, glass, and natural fibers are among the fibers now in use.

(Ramaswamy, 1983), found considerably high tensile strength of the natural air-dried jute fiber, due to immersion in an alkaline medium (pH value 11) for four weeks, a 5–32% loss could have occurred. However, (Zhu, 2020), reported a marginal loss while the fibers were embedded in cement concrete. Later (Zakaria, 2018), reported improved compressive, tensile and flexural using jute and yarn fibers in concrete. (Ahmed & Islam, 2018), Addition of small closely-spaced, uniformly distributed fibers act as crack arrester i.e. control cracking due to plastic shrinkage and to drying shrinkage, substantially increase static and dynamic properties. They also reduce the permeability of concrete and thus reduce bleeding of water. Fibers enhances concrete self-weight and could induce a balling effect during mixing, reducing workability.

(Aluko et al., 2020). (Islam & Hussain, 2012) and (Elsaid et al., 2011), reported that, the bark of the plant is the source of fibers. The plant could be up to 2.5m tall, with a stem diameter of around 25 mm at the base. First, the matured plants are wrapped into bundles and submerged underwater. The organic bark decomposed entirely during this period, (Hasan et al., 2020, p. 2); (Ahmad et al., 2021, p. 2); (Vishwanath et al., 2019), and (Kirupairaja et al., 2019).

This study came up with the Jute Fiber Modification, as addition to the existing reinforcement technique where by the fiber is modified with treatment of Alkali Sodium, called the sulphonation method which is more beneficial than other procedures to modify the properties of jute fiber. The Jute Fibers were treated with sulfite liquor, which was prepared by dissolving the measured amount of sodium sulphite or bisulfate with or without sodium carbonate or hydroxide at 165ºC for a definite period. $NaOH_2$ significantly improve the mechanical properties of concrete as compared to plain or unmodified fibers, (Datta et al., 2016). The modification techniques, such as chemical treatment or hybridization with other fibers, enhances the properties of jute fiber, improve its compatibility with concrete matrix & increase its reinforcing efficiency, (N. Nageswari & Dr. R. Divahar, 2022) and (Rashid et al., 2019). The treatment of the Jute Fiber with alkali (NaOH) is applied to enhance its durability and clean the coir dust in its surface, (Asaduzzaman & Islam, 2023).

In this study, an experimental research methodology was implemented to investigate the effects of the impact of modified Jute Fiber Reinforcement on Concrete Performance. The experiment prepared 36 cubes, 36 cylinders and 36 beams respectively, with varying fiber contents of 0%, 1%,1.2% and 2% and including varying curing times, followed by mechanical tests which measure compressive, flexural and split tensile strengths. The results were analyzed quantitatively, including statistical analysis such as graphs and ANOVA, to interpret the experimental data.

Moreover, the Linear Regression and Random Forest were the only two machine learning models used in the study, to predict the concrete strength also, based on their fiber percentages and curing times. In the study, to analyze the possible prediction results of the Machine learning used, the model performance was evaluated using the metrics of R-Squared and Mean-Squared Error (MSE). This combination of experimental and computational techniques provided a robust framework for analyzing the performance of the Modified jute fiber reinforcement on concrete properties. Lastly, this study highlighted that, not everyone especially in Developing Countries can afford the Artificial Fibers, but as the Natural fibers are more widely available, have low cost and strength enough for construction purposes, this is considered a solution and a good contribution to material sustainability.

II. Previous Studies:

This Article explores over 40 relevant topics from different journals and only few relevant experimental papers were summarized for Jute Fibers, and some of which are on Machine learning application in concrete performance. The other remaining papers were read, understood and further explained in the analysis.

i. Studies of Untreated Jute Fibers:

a. (Abdullah et al., 2022), Wrote on the "Effect of Jute Fiber on the Compressive Strength of Concrete," which was Published in the Malaysian Journal of Civil Engineering, Vol. 34:3 (2022). The study investigated the impact of varying jute fiber lengths (10mm and 15mm) at different percentages (0.1%, 0.2%, and 0.3%) on the compressive strength of concrete. A total of 42 concrete cylinders were tested, including normal concrete samples. The slump value was 75mm with a water-cement (W/C) ratio of 0.4. Results showed that increased fiber content decreased the slump, and the highest compressive strength was recorded at 0.1% fiber content for both fiber lengths. Compressive strength increased by 64.34% and 70.9% for 10mm and 15mm fibers, respectively, compared to normal concrete. However, higher fiber lengths and contents reduced strength.

b. (Ali et al., 2019), Has written his paper titled "Concrete Beams Strengthened with Jute Fibers," Published in the Civil Engineering Journal, Vol. 5, No. 4 (2019). The research explored the effects of jute fiber reinforcement on the performance of reinforced concrete (RC) beams. A total of 24 RC beams (150mm x 150mm x 1000mm) were divided into four groups: reference beams, beams strengthened with carbon fiber-reinforced polymer (CFRP), and beams reinforced with jute fiber-reinforced polymer (JFRP) strips of varying widths (5, 10, and 15 cm) and layers. The study found that increasing the width and number of jute fiber layers improved the beams' toughness, flexural strength, and load-carrying capacity, although wider strips slightly decreased ductility and stiffness.

c. **(Khan et al., 2023),** Wrote a paper on the "Effects of Jute Fiber on Fresh and Hardened Characteristics of Concrete with Environmental Assessment and is Published in the Journal of Buildings, Vol. 13, 1691 (2023). This study examined the effects of different jute fiber percentages (0%, 0.10%, 0.25%, 0.50%, 0.75%) on the compressive, tensile, and flexural strengths of concrete. Using Design Expert 13 software and response surface methodology (RSM), the study found that the optimal performance was achieved at 0.10% jute fiber content. Beyond this percentage, no significant improvement was observed. Jute fiber decreased the environmental impact of concrete production, as measured by eco-strength efficiency (ESE). The highest slump was recorded at 0% fiber content, and the lowest at 0.75%, highlighting jute fiber's impact on workability.

d. **(Sahu & Tudu, 2020),** Published a Paper titled, **"**Effect of Jute Fiber Orientation and Percentage on Strength of Jute Fiber Reinforced Concrete." Published in the International Journal of Engineering and Advanced Technology (IJEAT) (2020). The research used jute fiber percentages of (0.15%, 0.25%, 0.35%, 0.5%) and orientations on the compressive and flexural strength of Jute Fiber. M30 grade concrete was used, and tests followed IS code recommendations. Results showed that jute fiber addition slightly improved compressive strength but significantly increased modulus of rupture (MR) in beams and slabs. A 0.25% fiber content enhanced MR by 15% in beams and 49% in slabs compared to plain concrete. The study concluded that jute fiber can improve concrete's tensile and flexural strength, making it suitable for use in partition walls, door/window panels, and inclined roofs, with further research needed to explore its durability and chemical affinity.

These four studies examine the effects of jute fiber on concrete and reinforced concrete structures. The first study highlighted the benefits of using 10mm and 15mm jute fibers in small percentages, which improved compressive strength, though higher fiber content and length reduced strength. The second study explored the use of jute fiber strips to reinforce RC beams, finding that increased strip width and thickness enhanced load-carrying capacity and toughness, though wider strips reduced ductility. The third study analyzed the environmental benefits of jute fiber, demonstrating that a 0.10% addition maximized concrete's compressive, tensile, and flexural strength while improving eco-efficiency. Finally, the fourth study showed that jute fiber, particularly at 0.25%, significantly improved the modulus of rupture, suggesting its potential for use in non-structural elements like partition walls and inclined roofs. Collectively, these studies affirm the potential of jute fiber as a sustainable reinforcement material in concrete applications.

ii. **Studies on Treated Jute Fibers:**

a. **(Lasiyal et al., 2016).** Wrote on "Experimental Study of Concrete Additive Jute as Geotextile Material" and is Published in the International Journal of Engineering Research & Technology (IJERT), Volume 4, Issue 23 (2016). The study investigates the use of modified jute fiber as a concrete additive and geotextile material. Chemically and polymer-treated jute fibers, sized 2 to 6 cm, were mixed with concrete along with natural waste materials like coconut husk and wheat husk. The treatment process improved the surface of the fibers, reduced hydrophilicity, and prevented agglomeration. The results demonstrated enhanced compressive strength in cement concrete reinforced with treated jute fiber. The study also highlights the cost benefits of jute fiber in low-cost housing construction, as well as its applications in road pavement, erosion control, and soil stabilization.

b. **(Asaduzzaman & Islam, 2023),** Wrote a Paper titled "Using Jute Fiber to Improve Fresh and Hardened Properties of Concrete", Published in the Journal of Natural Fibers, Volume 20, No. 2 (2023). This research focuses on the effects of jute fiber on the compressive strength, splitting tensile strength, and plastic shrinkage cracking of Jute Fiber Reinforced Concrete (JFRC). Concrete mixes containing jute fiber proportions of 0.1%, 0.2%, 0.3%, and 0.4% were tested with fiber lengths of 20 mm and 25 mm. Shrinkage tests under controlled conditions revealed a significant reduction in crack area (up to 61%) and maximum crack width (62%). Compressive strength improved by up to 7% at low fiber content, while the highest strength increase (25%) was observed at 0.4% fiber content for 25 mm fibers. Treated fibers showed reduced strength and were less effective in minimizing crack formation.

c. **(Kabir et al., 2013).** Published in the Journal of Multifunctional Composites (2013), in the Journal of "Mechanical and Thermal Properties of Jute Fiber Reinforced Composites." The study examines the mechanical and thermal properties of jute fiber composites, focusing on the effects of alkali treatment (NaOH) on fiber structure. Alkali treatment improved the thermal stability and mechanical performance of jute fibers by removing hemicellulose, lignin, and other cellulosic components. When these treated fibers were incorporated into polyester matrices, the composites demonstrated improved flexural strength, compressive strength, and modulus, along with enhanced interfacial adhesion. Higher concentrations of NaOH (5-7%) resulted in better mechanical properties, highlighting the importance of optimizing fiber treatment for improved composite performance.

d. (Pantamanatsopa et al., 2014), Wrote on the "Effect of Modified Jute Fiber on the Mechanical Properties of Green Rubber Composite." Presented at the 11th Eco-Energy and Materials Science & Engineering (EMSES) conference, Published in Elsevier - Energy Procedia. The research explores the impact of varying jute fiber content on the mechanical properties of natural rubber (NR) composites. Composites with fiber of 0%, 10%, 20%, & 40% were prepared & tested for their mechanical properties, including modulus, hardness, and tensile strength. The study found that as fiber content increased, modulus & hardness improved, but tensile strength decreased. Untreated NR/jute composites performed better mechanically than treated ones, emphasizing the role of fiber distribution. The study concludes that cellulose fibers are effective reinforcements for NR matrices, especially when treated with DPNR latex, resulted in superior mechanical properties compared to ones treated with HANR.

These four studies collectively explore the use of jute fibers in enhancing concrete and composite materials. The first study investigates jute fibers as a geotextile material, showing their potential in improving concrete compressive strength while providing cost-efficient construction solutions. The second study examines the effect of jute fiber on concrete's mechanical properties, with significant improvements in shrinkage resistance and compressive strength at higher fiber content. The third research evaluates the mechanical and thermal properties of jute fiber reinforced composites, finding that alkali treatment optimizes fiber-matrix adhesion, improving composite performance. Lastly, the fourth study focuses on natural rubber composites, demonstrating that increasing jute fiber content improves hardness and modulus but reduces tensile strength, with untreated fibers providing better overall mechanical properties.

iii. Machine Learning Application on Concrete Performance:

a. **(Sultana et al., 2020),** Investigated on "An experimental investigation and modeling approach of response surface methodology coupled with crow search algorithm for optimizing the properties of jute fiber reinforced concrete", Published in the Journal of Construction and Building Materials. The study explores the effectiveness of natural jute fiber as a reinforcing material for concrete strength. It investigates the impact of jute fiber on compressive and tensile strengths in Jute Fiber Reinforced Concrete Composites (JFRCC). A combination of Response Surface Methodology (RSM) and Crow Search Algorithm (CSA) was utilized to predict and optimize the influencing variables—fiber length, volume, and water-cement (W/C) ratio. The optimal fiber length was 6 mm, fiber volume 0.2%, and W/C ratio 0.55. The model predicted compressive strength at 35.1 N/mm² and tensile strength at 3.5 N/mm² after 28 days of curing, which were validated experimentally within a 5% variation from predicted values.

b. **(Mai et al., 2023),** Performed a research on "Optimization of machine learning models for predicting the compressive strength of fiber-reinforced self-compacting concrete" Published in Frontiers of Structural and Civil Engineering. This paper addresses the challenge of predicting compressive strength (CS) in fiber-reinforced self-compacting concrete (FRSCC) using machine learning models. The study created a database of 381 samples and employed three models: artificial neural network (ANN), random forest (RF), and categorical gradient boosting (CatBoost). CatBoost outperformed the other models, achieving superior predictive abilities with a root mean square error (RMSE) of 2.639 MPa and a coefficient of determination (R^2) of 0.986 for the test dataset. Sensitivity analysis revealed that cement content, testing age, and superplasticizer content were the most critical factors influencing CS.

c. **(Raju et al., 2024),** Have conducted a research on "A Comparative Analysis of Machine Learning Approaches for Evaluating the Compressive Strength of Pozzolanic Concrete" is Published in IUBAT Reviews. This research focuses on applying machine learning techniques—artificial neural networks (ANN), random forest (RF), and gradient boosting regressor (GBR)—to predict the compressive strength of pozzolanic concrete. Using a dataset of 482 samples, the random forest (RF) model emerged as the best performer, achieving a coefficient of determination (R^2) of 0.976 during training and 0.964 in testing. The RF model demonstrated the lowest root mean square error (RMSE) of 2.84 MPa and 7.81 MPa during training and testing, respectively. The study highlights cement as the most influential parameter in predicting compressive strength and underscores the robustness of the RF model in concrete optimization.

These three studies focus on optimizing the properties of fiber-reinforced and pozzolanic concrete using various modeling techniques. The first study integrates response surface methodology and the crow search algorithm to optimize jute fiber reinforced concrete, achieving near-accurate experimental validation of its predictions. The second and third studies employ machine learning techniques to model and predict compressive strength in self-compacting and pozzolanic concrete, respectively, with both studies highlighting the effectiveness of random forest models in delivering precise predictions. The combination of optimization techniques and machine learning tools offers significant advancements in concrete material performance prediction.

III. MATERIALS AND METHODS:

1. Tests on Materials and Samples

This Section contains the description of Materials used; (cement, Fine aggregate, course aggregate, Jute Fiber and water admixture). Ordinary Portland cement (OPC) grade 43 is used, Coarse aggregate, fine aggregate, and jute fiber were utilized in this investigation. ***The Ordinary Portland cement (OPC)*** with a strength class of 52.5N was employed in this experiment. The cement took 45 minutes to set, and its early strength after two days was 20 MPa. The specific gravity of OPC is 3.12, and it is composed of 95-100 percent clinker and 0-5 percent gypsum. Then the ***Fine aggregates*** used consist of particles that pass through a 4.75 mm sieve, primarily including sand. They fill voids between coarse aggregates and enhance concrete workability. Size Range: 0.075 mm to 4.75 mm. The ***Coarse aggregates*** are larger particles retained on a 4.75 mm sieve. They provide strength and bulk to concrete which are categorized by sizes.

In this study, Sodium Hydro-oxide liquor was also used for the treatment of the Jute fiber, termed sodium hydro-oxide solution (NaOH). The process is called; the "Sulphonation Method". It has been noted that sulphonation of jute fiber is more beneficial than other existing procedures. The Raw Jute fibers were treated with sulphite liquor, which was prepared by dissolving the measured amount of sodium sulphite or bisulphate with or without sodium carbonate or hydroxide at 165ºC for a definite period. Moreover, in this Study, Portable water with a pH of 6.5-9.5 was used for mixing and curing, the water is obtained at the concrete lab in the civil engineering dept, faculty of Engineering, Mewar University. The sodium hydroxide used for modification of jute fiber is illustrated in figure 1, moreover, the Treated Jute fiber after modification was done is shown in the below figure 2:

Fig. 1: *NaOH* ***-*** *Used for Modification of Jute*

Fig. 2: *Modified Jute fiber*

The tests on materials, fresh and hardened concrete are; *Tests on Cement includes*, *the Specific Gravity, Fineness and Setting Time, then the Test that are done on Fine Aggregate* includes; *Specific Gravity, Water Absorption, Bulking, Fineness Modulus and Sieve Analysis*. The next was the *Tests on Coarse Aggregate; which are the Specific Gravity Test and Water Absorption Test.* Then the last Test on Material is the Tests on Sustainable Material (Treated Jute Fiber) and includes; *Water Absorption Test, Specific gravity Test, and Modification/Treatment of jute fibers with Selected Chemical I.e., NaOH Solution*

Secondly, we also have *Tests on fresh Concrete, and they the Slump test (Fluidity/Workability)* which was done for the various fresh concrete mixt including the control and modified Jute fiber mix. And lastly but not the least, is the *Major Tests* performed *on Hardened Concrete samples including* the; *Compressive Test, Flexural Strength Test and Split Tensile Strength Test* done on various samples of Concrete.

2. SAMPLE'S PREPARATION:

The treated Jute Fiber of 20mm uniform Lengths was added in the mix both in percentages 1, 1.5 and 2%. The Cube size is (0.15 X 0.15 X 0.15mm), then the RC beams is (150 X 150 X 700mm) lengths and the Cylinder is (150 dia. X 300 h) mm in length. This experiment tested 36 Cubes, Beams and Cylinders comprising of four groups, the First group consisted of 9 RC Control mix, without addition of jute. The second, third and fourth groups each consisted of nine (9) Samples also in the percentages; 1.0%, 1.5% and 20% with Constant Jute lengths of 20mm strengthened at random.

3. SUMMARY OF MIX PROPORTIONS, CALCULATION AND GRADE OF CONCRETE

Mix design was carried out by the IS Code 10262- 2019, with a slump of 3 into 4 in. Before mixing, all of the aggregates were soaked and surface dry (SSD). (IS Code & Jangeed, 2019). Initially, 75mm slump value was selected. For w/c ratio = 0.5, the amount of water, cement, and aggregate was calculated**.** A common reference mix proportion for M30 grade concrete used in this study (by weight) is approximately **1: 1.81: 2.71: 0.5** (Cement Sand: Aggregate), but this should be adjusted based on actual experimental results.

a. **Cement** = $\frac{394\text{kg}}{\text{m3}}$

b. **Water** = $\frac{197\text{kg}}{\text{m3}}$

c. Fine Aggregate (F.A) = $\frac{718.85kg}{\text{m3}}$

d. Coarse Aggregate = $\frac{1067.44kg}{\text{m3}}$

Mix Ratio: 1: 1.82: 2.71: 0.5

IV. SUMMARY OF MATERIALS BATCHED BY WEIGHT:

i. **Volume of Cubes:** (0.15 x 0.15 x 0.15) = 0.003375m^3 x 1.54.
ii. **Volume of Wet Cube =** 0.0051975m^3
iii. **Volume of Beams** (0.15 x 0.15 x 0.7) = 0.01575m^3 x 1.54.
iv. **The volume of Wet Beam =** 0.024255m^3
v. **Volume of Cylinder** (1.5 x 0.3)
vi. **Formula** = $\pi r^2 h$ = 3.14(r^{2}h) = 3.14 x (0.075^2 x 0.3) = 0.053m^3 x 1.54
vii. **Volume of Wet Cylinder** = 0.0816m^3

V.SUMMARY OF VOLUMES OF CUBES, BEAMS, AND CYLINDERS BATCHED BY WEIGHT

The Mix Proportions for Cubes are summarized in Table 1, Table 2 illustrated the Mix Proportions for Beams, then the Mix Proportion and Material Quantities for Cylinders are presented in Table 3. Lastly, the Overall Material Quantities for Cubes, Beams and Cylinders are listed in Table 4 below:

Table 1: *Cubes: Volume of 9 Cubes* ***= 0.0468m3***

% of jute	Cement	F.A	C.A	Water	Weight of Jute
0%	12.19kg	24.64kg	39.98kg	6.095kg	0kg
1%	12.19kg	24.64kg	39.98kg	6.095kg	12.19g/0.01219kg
1.5%	12.19kg	24.64kg	39.98kg	6.095kg	18.29g/0.01819kg
2%	12.19kg	24.64kg	39.98kg	6.095kg	24.38g/0.02438kg
Total	**48.76kg**	**98.56kg**	**159.92kg**	**24.38kg**	**0.05476kg**

Table 2: *Beams: Volume of 9 Beam* ***= 0.2183m3***

% of jute	Cement	F.A	C.A	Water	Weight of Jute
0%	56.84kg	114.95kg	192.56kg	28.42kg	0kg
1%	56.84kg	114.95kg	192.56kg	28.42kg	0.0568kg
1.5%	56.84kg	114.95kg	192.56kg	28.42kg	0.0853kg
2%	56.84kg	114.95kg	192.56kg	28.42kg	0.1137kg
Total	**227.36kg**	**459.8kg**	**770.24kg**	**113.68kg**	**0.2558kg**

Table 3: *Cylinders: Volume of 9 Cylinders* ***= 0.0816m3***

% of jute	Weight of Cement	F.A	C.A	Water	Weight of Jute
0%	21.25kg	42.97kg	75.10kg	10.63kg	0kg
1%	21.25kg	42.97kg	75.10kg	10.63kg	0.0213kg
1.5%	21.25kg	42.97kg	75.10kg	10.63kg	0.0319kg
2%	21.25kg	42.97kg	75.10kg	10.63kg	0.0425kg
Total	**85.0kg**	**171.88kg**	**300.4kg**	**42.52kg**	**0.0957kg**

Table 4: *Overall Total Material's Weight for the 36 Cubes, Beams, and Cylinders each:*

% of jute Addition	Total Cement	Total F.A	Total C.A	Total Water	Total Jute
0%	361.12kg	730.24kg	1230.56kg	180.58kg	0kg
1%	324.01kg	655.22kg	1096.29kg	162.005kg	0.0903kg
1.5%	324.01kg	655.22kg	1096.29kg	162.005kg	0.1354kg
2%	324.01kg	655.22kg	1096.29kg	162.005kg	0.1806kg
Total	**1296.04kg**	**2620.88kg**	**4385.16kg**	**648.02kg**	**0.4063kg**

VI.EXPERIMENTAL PROCEDURES AND VISUAL DOCUMENTATION

Firstly, Cement was stored in a moisture-proof container to prevent premature hydration and handling issues, as per general good practices in concrete work. Then the Fine and coarse aggregates were kept damp and dry for 24 hours before mixing. The fine aggregates used were only those that passed through a 5mm sieve, while Coarse aggregates were those that passed through a 20mm sieve. The Treated Jute fibers, required for reinforcement, were cut to a uniform length of 20 mm as shown in figure 3, this is done in order to ensure effective dispersion and reinforcement in the concrete mix. Figure 4 shows the 20mm coarse aggregate after sieving.

Fig.3: *Cutting of Jute (20mm)*

Fig.4: *20mm Coarse Aggregates*

In this study, mixing was conducted with a shovel on a clean and level floor. The concrete mix proportion used for the study is **1: 1.81: 2.71: 0.5** (Cement: Fine Aggregate: Coarse Aggregate: Water). This mix ratio was carefully selected based on the requirements of the M30 grade and the incorporation of jute fibers. The process of mixing with jute fibers is demonstrated in figure 5, whereby the casting, filling and tamping of concrete in a mold is shown in figure 6 below.

Fig. 5: *Mixing with Jute*

Fig. 6: *Casting and Filling*

The slump test measures the workability or consistency of fresh concrete. It assesses how easily the concrete can be mixed, placed, and compacted. A higher slump indicates a more workable mix, while a lower slump suggests a stiffer mix. The equipment used is called a slump cone (a truncated cone with a height of 300 mm, top diameter of 200 mm, and bottom diameter of 100 mm), and a tamping rod. Therefore, the slump value for 1% jute fiber content is displayed in figure 7, likewise figure 8 shows 0% slump

Figure 7: *1% Slump*

Figure 8: *0% Slump*

Concrete samples were casted into standard molds as per the requirements of the tests. For this study, molds for cubes, beams, and cylinders were used to assess different properties of the concrete. The Molds were cleaned and oiled to prevent the concrete from sticking and to ensure easy removal of specimens after curing. The preparation of molds aligns with standard practices as outlined in IS 456:2000 - Code of Practice for Plain and Reinforced Concrete. To ensure proper compaction and eliminate air bubbles, a tamping rod was used to manually tamp each layer of concrete, ensuring that the mix was compacted adequately and that no voids were present. Also a mechanical vibrator was employed to achieve thorough compaction of the concrete. This method helps in achieving the desired density and workability of the concrete, as recommended in IS 456:2000. The casting and tamping process of concrete is presented in figure 9, then figure 10 displayed the casted sylinders:

Figure 9: *Casting and Tamping*

Figure 10: *Casted Cylinder Samples*

After the initial curing period, which typically lasts for 24 to 48 hours, the concrete specimens were carefully removed from the molds. Once the concrete was cast and finished, it was cured to prevent drying out and to ensure proper hydration. Curing was done by covering the molds with wet burlap or applying curing compounds as per the guidelines in IS 456:2000 All concrete products were stored at room temperature, ranging from 20 to 30°C. Proper curing & storage are essential to achieve the desired strength and durability.

The specimens were placed in a curing tank for continued curing until they reached the desired age for testing. They must be properly cured to achieve its greatest properties. After 24 hours, they were removed from the molds and wet cured for 7, 14, & 28 days at 23.17°C, & this is called wet curing. The cube specimens used for testing are illustrated in figure 11, figure 12 shows cube specimens curing inside water tank and figure 13 displayed cylinders inside water tank also.

Figure 11: Cubes

Fig. 12: Curing in a water tank

Fig. 13: Cylinders Curing

VII. TESTING OF CONCRETE SAMPLES

1. Compressive Strength Test:

The compressive strength test is the ability of concrete to withstand axial loads. The specimens were examined by the Universal / Compressive Testing Machine (U / CTM) after 7 and 28 days of curing. For equal load distribution, bearing plates were installed. A UTM constantly applied compressive stress without shock. The load was gradually increased at a rate of 2mm/min until the specimens failed. During the test, the maximum load borne by the compression test machine was recorded. By dividing the load at failure by the area of the specimen, the compressive strength of the concrete was estimated. Then, figure 14 presented the cube after compressive strength test, figure 15 illustrated the result on the screen of the CTM after testing, and the failed cube samples were shown in figure 16 below:

Fig. 14: *Cube after Testing.*

Fig. 15: *Recording Results.*

Fig. 16: *Failed Samples*

2. Flexural Strength Test:

The flexural strength test measures the ability of concrete to withstand bending forces. This test is critical for assessing the performance of concrete beams under flexural stress. A Universal Testing Machine (UTM) or a specialized Flexural Testing Machine is used for this test. The UTM typically has accessories or attachments for performing flexural tests. Therefore, figure 17 shows the flexural strength test setup and figure 18 illustrated failed beam sample immediately after failure in the UTM.

Fig. 17: Setting Distance b/w Support

Fig. 18: Failed Beam

3 Split Tensile Strength Test:

The Split Tensile Strength Test is used in this study, to determine the tensile strength of a material, typically concrete. Unlike direct tensile tests, which are challenging to conduct on concrete due to their low tensile strength and brittleness, the split tensile test provides a practical method for evaluating tensile strength indirectly. The tensile strength test measures the maximum amount of tensile stress a material can withstand before failing. During this test, a sample is subjected to a uniaxial tensile force until it breaks, providing direct data on the material's ultimate tensile strength, yield strength, and elongation. This method is widely used for metals, polymers, and fibers. In contrast, the split tensile test, or Brazilian test. The failed cylinder samples after split tensile test are shown in figure 19, then setup and loading of cylinder sample is presented in figure 20 below:

Figure 19: *Failed Cylinder Samples*

Figure 20: *Split Tensile Test*

8. WATER ABSORPTION TEST

The water absorption test measures the ability of materials to absorb water, which is critical for understanding their suitability for construction purposes. This test is important because it affects the material's strength, durability, and overall performance in concrete and other construction applications. Water absorption is determined by immersing the material in water for a specified period, and then measuring the increase in weight due to water absorption. The weighing process during the water absorption test is illustrated in figure 21, then figure 22 shows an oven for drying of sample.

Fig. 21: *Weighing Filled Pycno.*

Fig 22: *An Oven*

9. SIEVE ANALYSIS

This process helps determine the particle size distribution of the sample, which is essential for various applications in construction and materials science. Figure 23 illustrated the sieve analysis procedure and the sieve stack for sieve analysis is demonstrated in figure 24 below:

Fig 23: *Weighing.*

Fig 24: *Sieve Stack*

VIII. DATA ANALYSIS METHODS:

This statistical methods, software tools and machine learning were used in the study, along with the assumptions and considerations for each method. The ANOVA is used to compare means among three or more groups, to determine if there are any statistically significant differences between them. For instance, it can be used to compare groups. **ANOVA:** Assumes normality of residuals, homogeneity of variances, and independence of observations and it has also been used for Hypothesis testing, because it helps to determine if there are statistically significant differences in concrete strength (measured in terms of compressive, flexural and split tensile strengths) across different levels of jute fiber contents.

The **Mean (MPa)** was obtained and recorded from the experimental Tests of Compressive, Flexural and Split Tensile Strengths Tests, it assumes normality of the data distribution and homogeneity of variances. To check normality, the use of visual inspection (e.g., histograms, Line graph) or statistical tests were employed.

Then the **Machine Learning Models and Simulation** adopted the "Multiple Linear regression and Random Forex" to predict the concrete strength based on curing time and fiber content. Model performance was evaluated using metrics such as Mean-Squared Error (MSE) and R-Squared to assess prediction accuracy. These tools provide a range of statistical functions and visualizations for data analysis. The Random forest algorithm workflow and the Multiple Linear Regression algorithm workflow were best introduced in figure(s) 25 and 26 below in order to make it easier to understand the workflow of each model:

Figure 25: *Flowchart for Random Forest Algorithm Procedure*

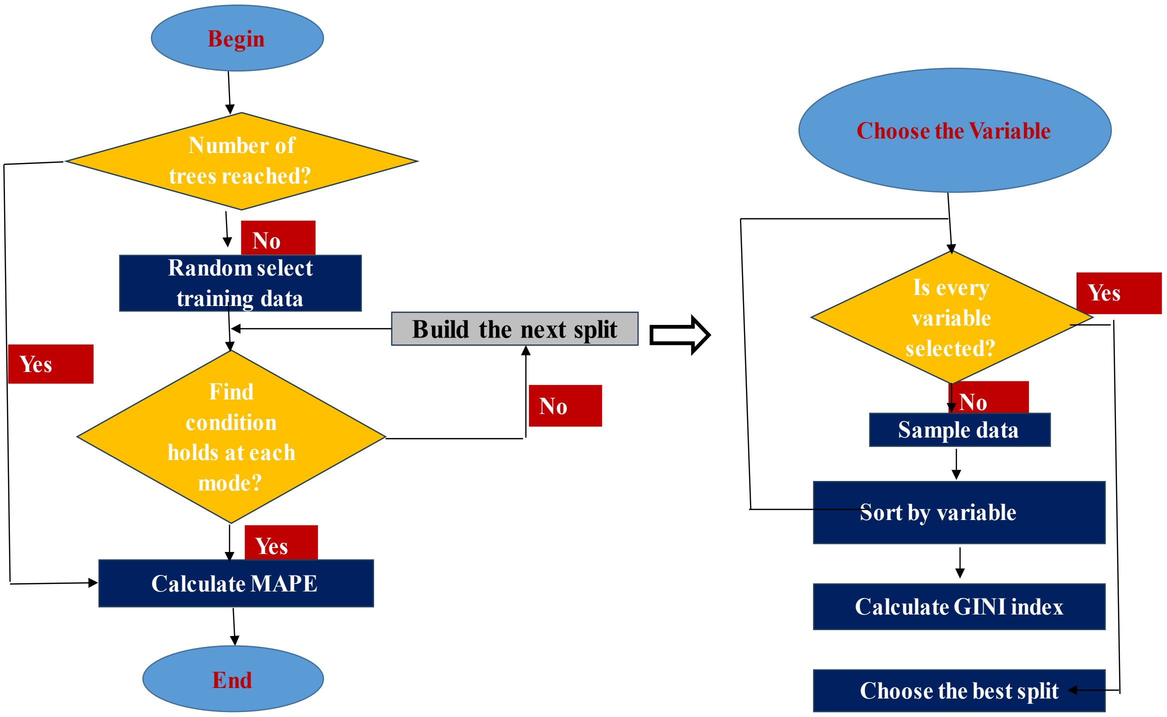
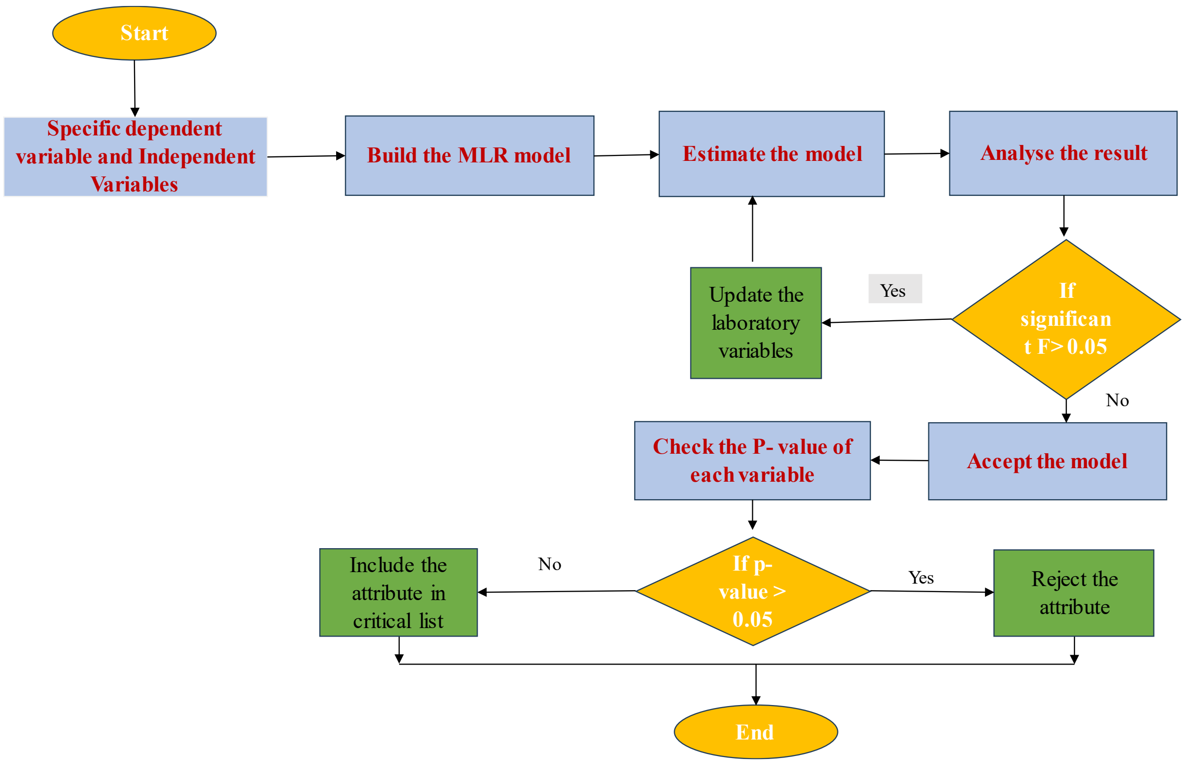


Figure 26: *Flowchart for Multiple Linear Regression Algorithm Procedure*



IX. RESULTS AND DISCUSSIONS

9.1. Introduction

The entire experimental Results of Material properties, Fresh and Hardened properties of Treated Jute Fiber Reinforcement used in the study were reported here. The results were represented in tabular form including the Average mean in Mega-Pascals and the graphical illustrations of the findings. It also contained the Results of the Machine Learning Algorithms obtained from the experimental data based on the tread jute fiber contents and curing times.

9.2. PRESENTATION OF EXPERIMENTAL RESULTS:

i.MATERIAL PROPERTIES

The results of specific gravity and water absorption for coarse aggregate are presented in table 5, then the properties of fine aggregate are summarized in table 6, And also, the test results for treated jute fiber illustrated in the below table 7:

Table 5: *Specific Gravity and Water Absorption of Coarse Aggregate*

S/No.	Parameters	Trial I	Trial II	Trial III
1.	Weight of empty basket in water (B)	616	614	613
2.	Weight of the saturated surface – dry aggregate in air (C)	3001	3012	3016
3.	Weight of oven-dried aggregate in air (D)	2992	3002	3008
4.	Specific gravity = {D/[C-(A-B)]}	2.71	2.69	2.70
5.	Average specific gravity		2.70	
6.	Apparent Specific gravity = [D/(D-(A-B))]	2.73	2.72	2.73
7.	Average apparent specific gravity		2.73	
8.	Water absorption in (%) = [(C-D)/D] X 100	0.30	0.33	0.27
9.	Average water absorption %		0.30	

Table 6: *Specific Gravity and Water Absorption of Fine Aggregates*

S/N	Parameters	Trial I	Trial II	Trial III
1.	Weight in g of saturated surface-dry sample(A)	456	461	452
2.	Weight in g of pycno. containing sample & filled with distilled water (B)	1809	1808	1810
3.	Weight in g of pycnometer filled with distilled water only (C)	1520	1519	1521
4.	Weight in g of oven-dried sample only (D)	448	451	444
5.	Specific gravity = {D/[A-(B-C)]}	2.68	2.62	2.72
6.	Average specific gravity		2.67	
7.	Apparent Specific gravity = [D/(D-(B-C))]	2.82	2.78	2.86
8.	Average apparent specific gravity		2.82	
9.	Water absorption in (%) = [(A-D)/D] X 100	1.79	2.2	1.80
10.	Average water absorption %		1.93	

Table 7: *Specific Gravity and Water Absorption of Treated Jute Fiber*

S/N	Parameters	Trial I	Trial II	Trial III
1.	Weight in g of saturated surface-dry sample(A)	44	45	43
2.	Weight in g of pycn. containing sample & filled with distilled water (B)	1532	1541	1531
3.	Weight in g of pycnometer filled with distilled water only (C)	1521	1523	1520
4.	Weight in g of oven-dried sample only (D)	32	36	33
5.	Specific gravity = {D/[A-(B-C)]}	0.97	1.19	1.03
6.	Average specific gravity		**1.06**	
7.	Apparent Specific gravity = [D/(D-(B-C))]	1.5	2.0	1.5
8.	Average apparent specific gravity		**1.67**	
9.	Water absorption in (%) = [(A-D)/D] X 100	37.50	25.00	30.30
10.	Average water absorption %		**30.93**	

ii.PARTICLE SIZE DISTRIBUTION:

The Sieve Analysis results for Fine Aggregate are displayed in table 8 below:

Table 8: *Sieve Analysis of Fine Aggregate*

Sieve Size	Weight of Sieve (g) (g)	Weight of Sieve + Sample Retained (g))	Weight of sample Retained (g)	Percentage retained (%)	Cumulative percentage Retained (%)	Percentage passing (%)
4.75mm	407	472	65	6.54	6.54	93.46
2.36mm	410	510	100	10.04	16.58	83.42
1.18mm	355	563	208	20.88	37.46	62.54

600µm	392	586	194	19.48	56.94	43.06
300µm	337	620	283	28.41	85.35	14.65
90µm	306	437	131	13.15	98.5	1.5
75µm	336	345	9	0.90	99.4	0.6
Pan	364	370	6	0.60	100	0
Total			**996**	**100**		

iii.PROPERTIES OF FRESH CONCRETE:

The Slump values and workability results are presented in the below figure 9:

Table 9: *Slump Values/Workability*

S/N.	Samples (%Jute Fiber added)	Slump	W/C Ratio	Remark
1.	Slump Value of 0%	75mm	0.5	Normal workability
2.	Slump Value of 1%	12mm	0.5	Significantly reduced workability
3.	Slump Value of 1.5%	7mm	0.5	Severely reduced workability
4.	Slump Value of 2%	3mm	0.5	Reduced workability

iv.MECHANICAL (HARDENED) PROPERTIES OF CONCRETE

The overall strength test results for different curing days are given in table 10 below:

Table 10: *Overall Strength Test Results with Varying Fiber Contents and Curing Days*

Sample ID	Fiber (%)	Curing Age	Compressive (MPa)	Flexural (MPa)	Split Tensile (MPa)
TJF0		7	16.2	4.4	2.2
TJF0	**0%**	14	24.0	5.3	2.6
TJF0		28	33.6	6.5	3.2
TJF1		7	19.2	5.3	3.2
TJF1	**1%**	14	27.1	6.5	3.8
TJF1		28	38.0	7.8	4.7
TJF1.5		7	18.1	5.5	3.0
TJF1.5	**1.5%**	14	26.4	6.6	3.6
TJF1.5		28	35.0	7.5	4.2
TJF2		7	17.1	5.2	2.6
TJF2	**2%**	14	25.4	6.4	3.2
TJF2		28	34.1	7.3	3.8

9.3 DATA ANALYSIS AND INTERPRETATION:

This section shows the analysis of the data presented above, which includes Bar charts, Histogram, Line graphs using the Average Mean Scores (MPa) of each of the experimental results. The analysis is already done in the tables above, showing the average of the complete samples tested in the study.

9.3.1 Descriptive Statistics

1. Measures of Central tendency / Average Mean Strength in Mega-Pascal (MPa)

In this Section, the experimental results were represented using graphical representations and illustrations, the Mean is already found, that is the Mega-pascals of each of the, Material, Fresh, Physical and Hardened Mechanical Properties of the Treated Fiber Reinforcements. The Averages (Mean), as in the Tables; 7, 8, 9, and 10 of the samples were used in plotting the graphs. The results of slump workability tests are plotted in figure 28, figure 29 shows the sieve analysis results, figure 30, 31 and 32 displayed the compressive strength results at 7,14 and 28 days. Moreover, figure(s) 33-35 presented the flexural strength results at 7,14 and 28 days. Figure(s) 36-38 displayed the split tensile strength graphs at 7,14 and 28 days. Comparisons of compressive, flexural and split tensile strengths are illustrated in figure(s) 39,40,41,42 and 43.

2. Graphical Representation of Results (Histograms, Bar charts & Line graphs).

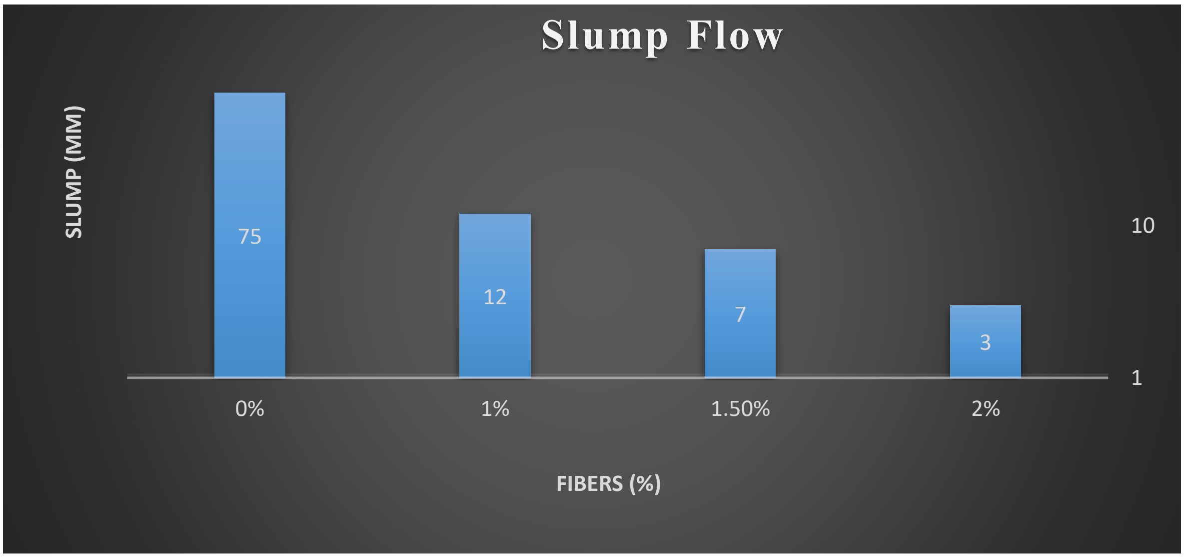


Figure 28: Slump (Workability) Test Results

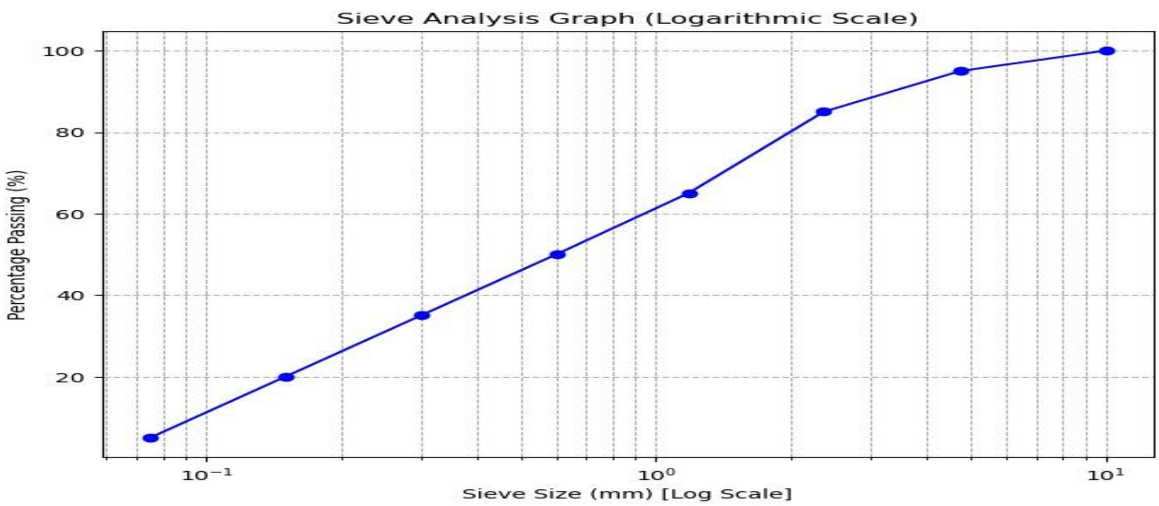


Figure 29: *Sieve Analysis Results Graph*

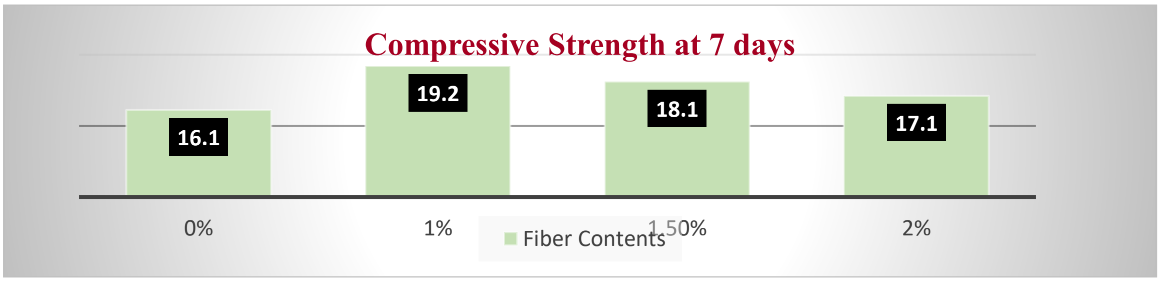


Figure 30: *Compressive Strength - 7 days Results*

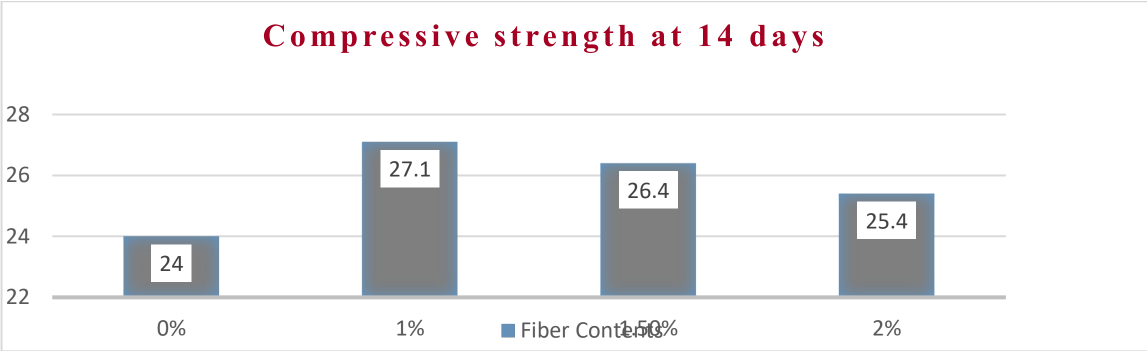


Figure 31: *Compressive Strength - 14 days Results*

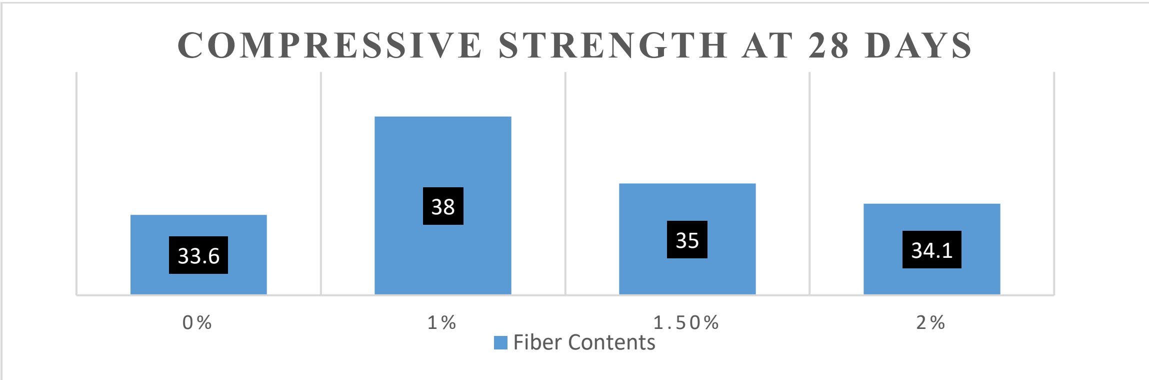


Figure 32: *Compressive Strength - 28 days Results*

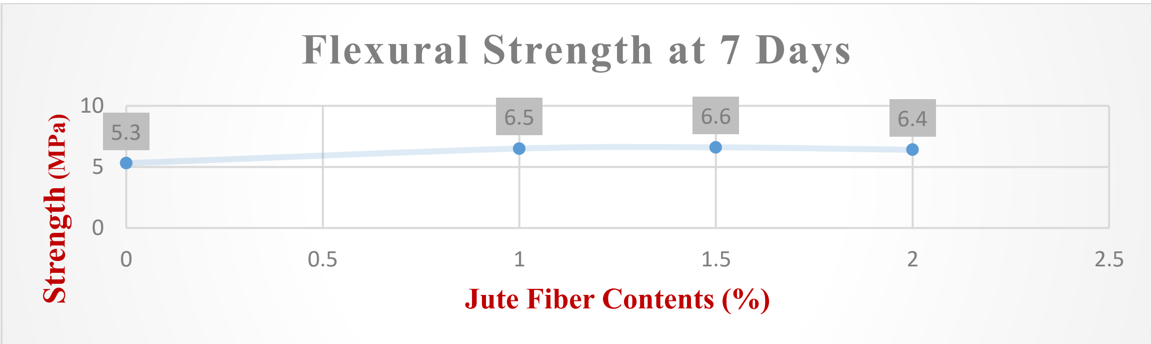


Figure 33: *Flexural Strength - 7 days Results*

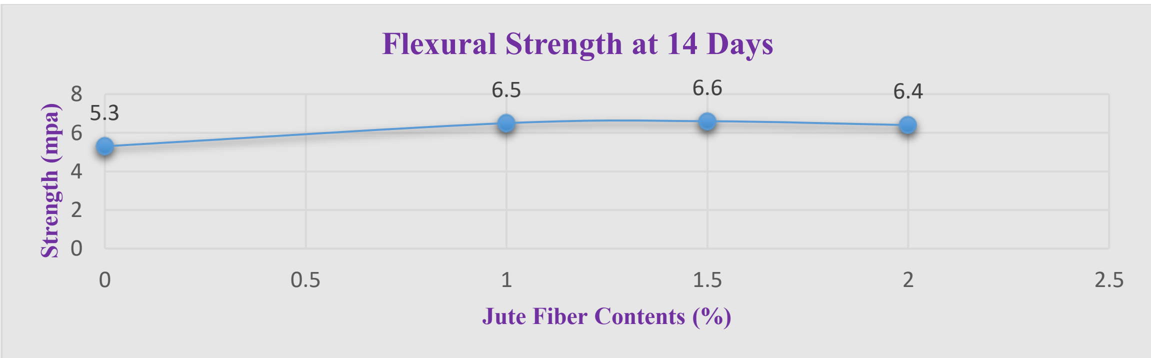


Figure 34: *Flexural Strength - 14 days Results*

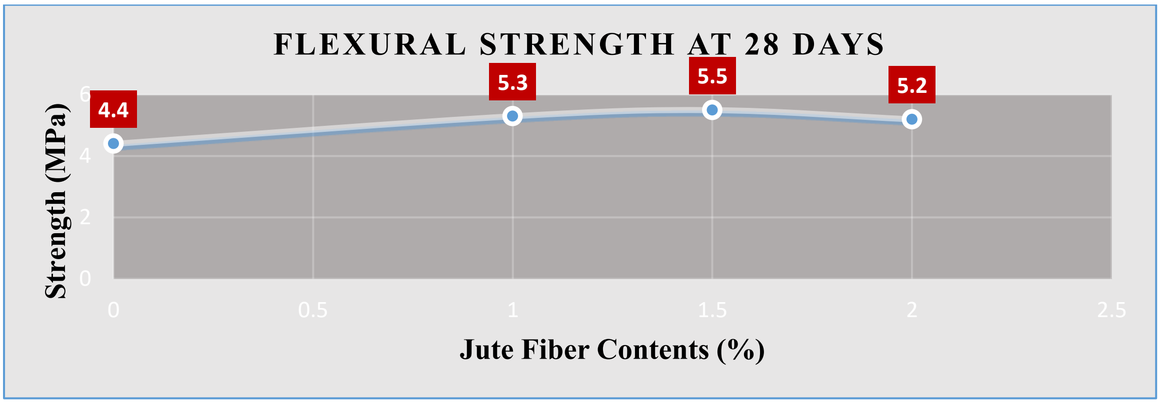


Figure35: *Flexural Strength Results at 28 Days*

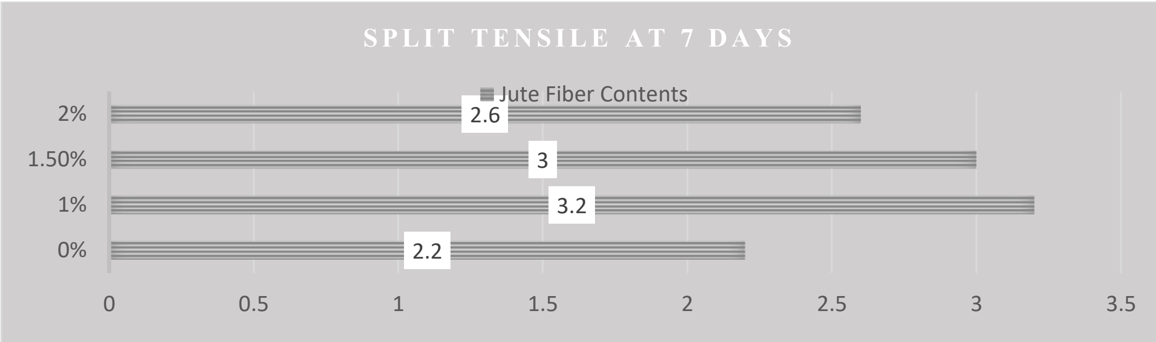


Figure36: *Split Tensile - 7 days Results*

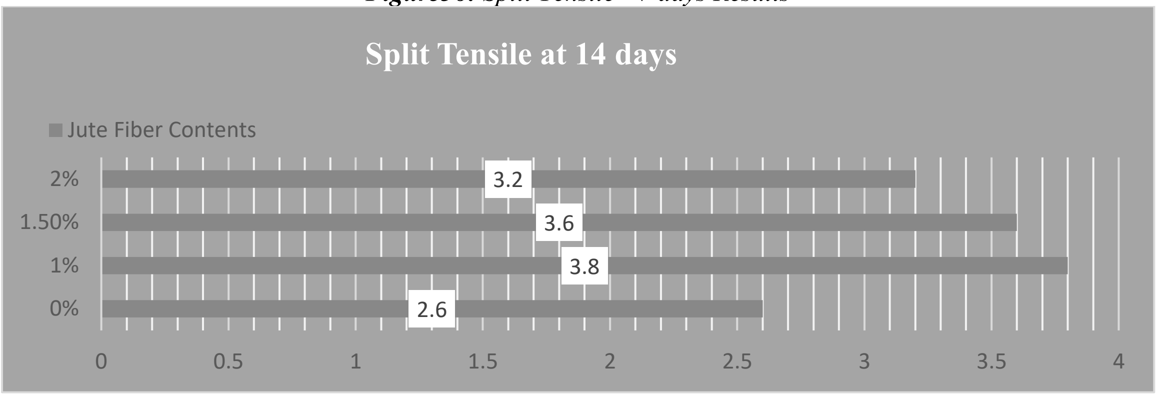


Figure 37: *Split Tensile - 14 days Results*

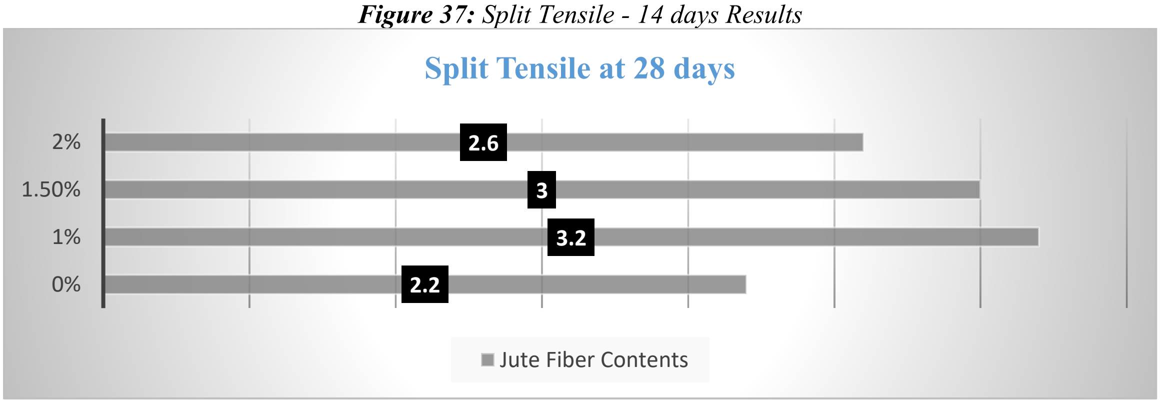


Figure 38: *Split Tensile - 28 days Results*

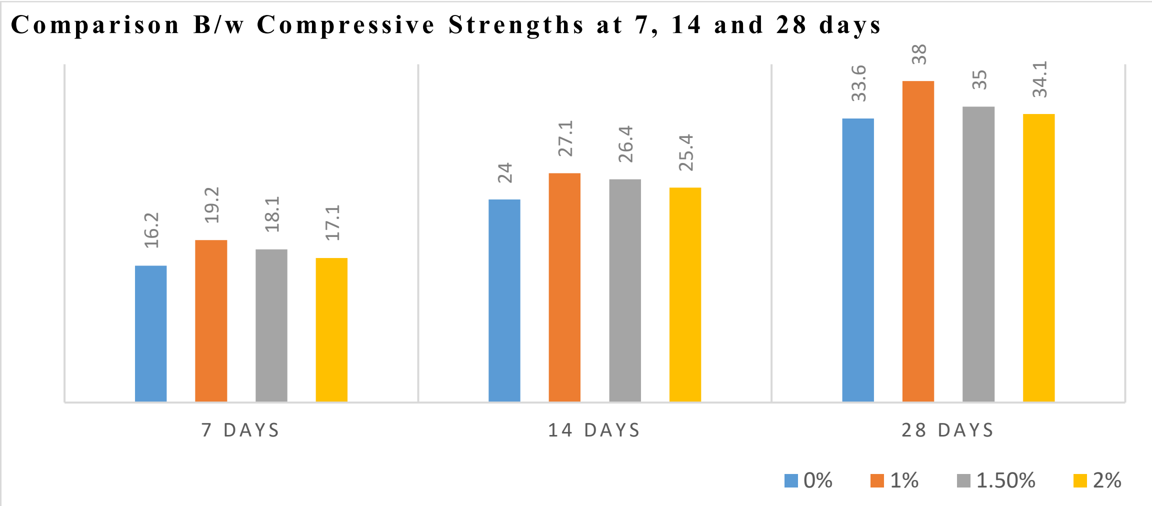


Figure 39: *Comparison between Compressive Strengths at 7, 14 and 28 days*

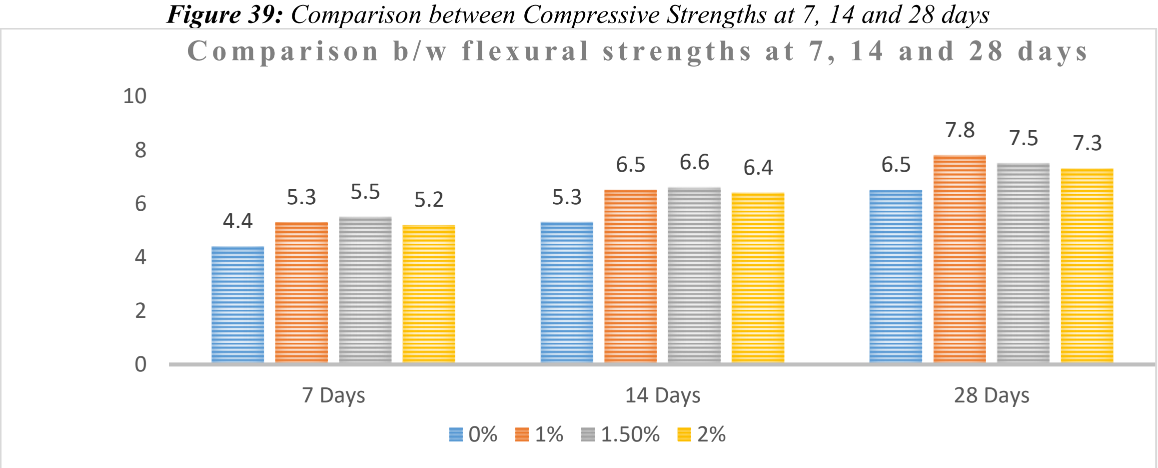


Figure 40: *Comparison between Flexural Strengths at 7, 14 and 28 days*

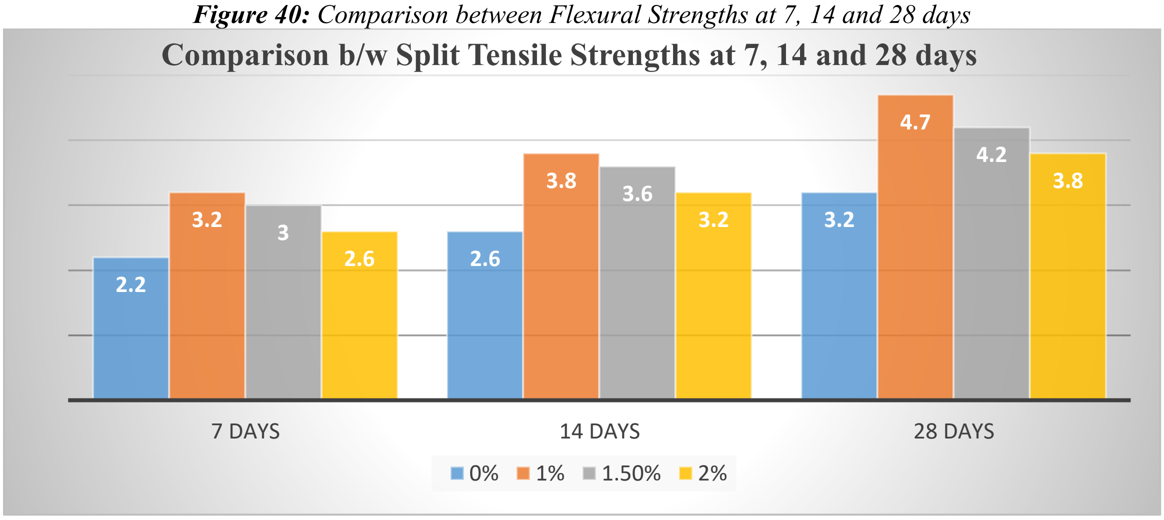


Figure 41: *Comparison between Split Tensile Strengths at 7, 14 and 28 days*

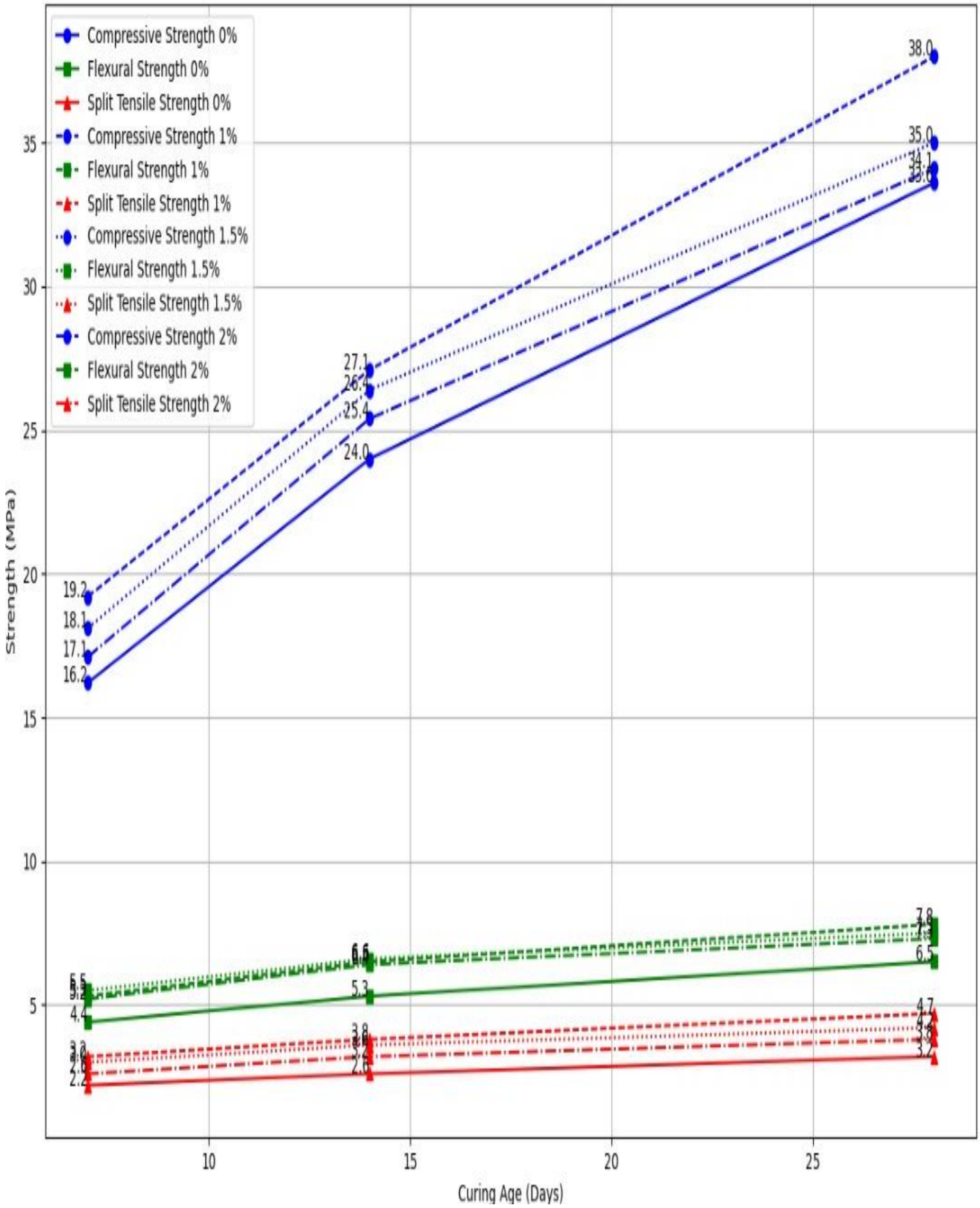


Figure 42: *Relationship Between CS, FS and SPT over time (Curing Ages) for different Fiber Contents*

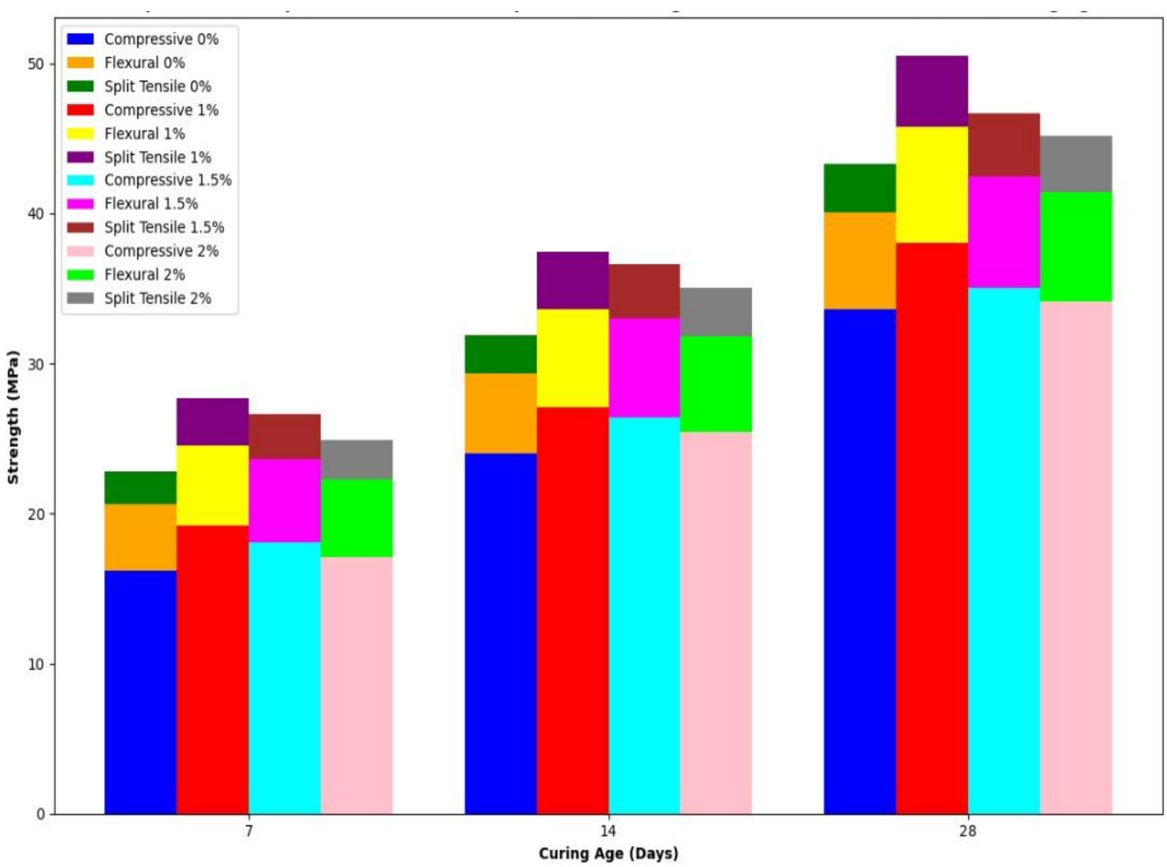


Figure 43: *Comparison Between CS, FS and SPT at Various Fiber Contents & Curing age*

9.4 Inferential Statistics

9.4.1 Parametric Correlation tests: The following Parametric test is Conducted in the study**;**

1. Analysis of Variance (ANOVA) Results:

This is used to check if there are significant differences between groups, **If the p-value is less than the significance level (commonly 0.05),** reject the null hypothesis, indicating a significant effect of fiber content on the respective strength property. But **If the p-value is greater than the significance level,** do not reject the null hypothesis, indicating no significance effect. Below is the hypothesis used for the research:

- **Ho1.** The incorporation of modified jute fibers in concrete doesn't significantly decrease its compressive strength.
- **Ho2.** The incorporation of modified jute fibers doesn't significantly diminish the Flexural Strength.
- **Ho3.** The use of jute fibers in concrete doesn't significantly reduce the Split Tensile Strength. The ANOVA results for compressive, flexural and split tensile strengths are summarized in Table 11 below:

Table 11: *Compressive, Flexural and Split Tensile Strengths ANOVA Table*

ANOVA Table for Compressive Strength				
	Sum. Sq.	**df**	**F**	**PR(>F) / P-Value**
C (Fiber Content)	20.110000	3.0	0.086847	0.965281
Residual	617.486667	8.0	NaN	NaN
ANOVA Table for Flexural Strength				
C (Fiber Content)	2.550000	3.0	0.691995	0.582174
Residual	9.826667	8.0	NaN	NaN
ANOVA Table for Split Tensile Strength				
C (Fiber Content)	2.562500	3.0	2.213823	0.164077
Residual	3.086667	8.0	NaN	NaN

9.5 Realization of Machine Learning Results

9.5.1 Multiple Regression Model Analysis

The Multiple Regression analysis is done with **statsmodels,** used to fit an OLS regression model and generate a summary. Then**, Sns.pairplot,** helps in visualizing the relationships between the variables**.** This helps to understand the relationship between the dependent and independent variable, it is a machine learning algorithm as used here, to predict unseen data from training and generalize pattern. And it is also used as a component in the simulation when modeling complex systems and forecasting outcomes. Table 12 presented the OLS Regression Result for compressive Strength.

Table 12: *OLS Regression Result*

OLS Regression Results			
Dep. Variable:	Compressive Strength	**R Squared (R^2):**	0.948
Model:	OLS	**Adj. R Squared (R^2):**	0.929
Method:	Least Squares	**F Static:**	48.72
Date:	wed, 11 Sep 2024	**Prob (F Static):**	1.75e-05
Time:	16:23:14	**Long Likelihood:**	- 23.113
No. Observation:	12	**AIC:**	54.23
Df Residual:	8	**BIC:**	56.16
Df Model:	3		
Covariance Type:	Non robust		

1. Multiple Regression for Compressive Strength

Table(s) 13: *Multiple Regression for Compressive Strength (OLS Regression Results)*

	Coef.	**Std Err.**	**t**	**P>[t]**	**[0.025**	**0.975]**
Const	12.0057	2.267	5.295	0.001	6.778	17.234
Fiber Content	0.8171	1.684	0.485	0.641	- 3.066	4.701
Curing Age	0.8336	0.122	6.810	0.000	0.551	1.116
Fiber Cont. x Curing Age	- 0.0195	0.091	- 0.214	0.836	- 0.229	0.190

Omnibus:	1.813	**Durbin-watson:**	**1.765**
Prob (Omnibus):	0.404	**Jarque – Bera (JB):**	**1.000**
Skew:	0.349	**Prob (JB):**	**0.606**
Kurtosis:	1.770	**Cond. No.**	**139**

2. Multiple Regression Analysis for Flexural Strength:

Table(s) 14: *Multiple Regression for Flexural Strength (OLS Regression Results)*

Dep. Variable:	Flexural Strength	**R Squared (R^2):**	0.879
Model:	OLS	**Adj. R Squared (R^2):**	0.834
Method:	Least Squares	**F - Statistic:**	19.37
Date:	Thu, 12 Sep 2024	**Prob (F Statistic):**	0.000502
Time:	09:14:33	**Long - Likelihood:**	- 4.5420
No. Observation:	12	**AIC:**	17.08
Df Residual:	8	**BIC:**	19.02
Df Model:	3		
Covariance Type:	Non robust		

	Coef.	**Std Err.**	**t**	**P>[t]**	**[0.025**	**0.975]**
Intercept	3.9171	0.482	8.120	0.000	2.805	5.030
Fiber Content	0.5514	0.358	1.539	0.162	- 0.275	1.378
Curing Age	0.1049	0.026	4.027	0.004	0.045	0.165
Fiber Cont. : Curing Age	- 0.0037	0.019	- 0.190	0.854	- 0.048	0.041

Omnibus:	0.823	**Durbin-watson:**	1.276
Prob (Omnibus):	**0.663**	Jarque – Bera (JB):	**0.711**
Skew:	**0.330**	Prob (JB):	**0.701**
Kurtosis:	**2.007**	**Cond. No.**	**139**

Notes: Standard Errors assume that the covariance matrix of the errors is correctly specified.

	Fiber Content	Curing Age	Flexural Strength	Predicted Flexural Strength
1	0.0	7	4.4	4.651429
2	0.0	14	5.3	5.385714
3	0.0	28	6.5	6.854286
4	1.0	7	5.2	5.177143
5	1.0	14	6.5	5.885714
6	1.0	28	7.8	7.302857
7	1.5	7	5.5	5.440000
8	1.5	14	6.6	6.135714
9	1.5	28	7.5	7.527143
10	2.0	7	5.2	5.702857
11	2.0	14	6.4	6.385714
12	2.0	28	7.3	7.751429

3. Multiple Linear Regression Analysis for Split Tensile Strength:

Table(s) 15: *Multiple Regression for Split Tensile Strength (OLS Regression Results)*

Dep. Variable:	Split Tensile Strength	**R Squared (R^2):**	0.632
Model:	OLS	**Adj. R Squared (R^2):**	0.493
Method:	Least Squares	**F - Statistic:**	4.570
Date:	Thu, 12 Sep 2024	**Prob (F Statistic):**	0.0381
Time:	09:16:00	**Long Likelihood:**	- 6.5168
No. Observation:	12	**AIC:**	21.03
Df Residual:	8	**BIC:**	22.97
Df Model:	3		
Covariance Type:	Non robust		

	Coef.	Std Err.	t	P>[t]	[0.025	0.975]
Intercept	12.1329	0.569	3.751	0.006	0.821	3.444
Fiber Content	0.2486	0.422	0.588	0.572	- 0.726	1.223
Curing Age	0.0531	0.031	1.731	0.122	- 0.018	0.124
Fiber Cont. : Curing Age	0.0033	0.023	0.146	0.888	- 0.049	0.056

Omnibus:	**1.977**	Durbin-watson:	**0.792**
Prob (Omnibus):	0.372	**Jarque – Bera (JB):**	1.130
Skew:	0.445	**Prob (JB):**	0.568
Kurtosis:	1.788	**Cond. No.**	139

Notes: Standard Errors assume that the covariance matrix of the errors is correctly specified.

S/N	Fiber Content	Curing Age	Split Tensile Strength	Predicted Flexural Strength
1	0.0	7	2.2	2.504898
2	0.0	14	2.6	2.876939
3	0.0	28	3.2	3.621020
4	1.0	7	3.2	2.776735
5	1.0	14	3.8	3.172041
6	1.0	28	4.7	3.962653
7	1.5	7	3.0	2.912653
8	1.5	14	3.6	3.319592
9	1.5	28	4.2	4.133469
10	2.0	7	2.6	3.048571
11	2.0	14	3.2	3.467143
12	2.0	28	3.8	4.304286

9.6: Visualization of Machine Learning Results:
The Correlation matrices and Relationships using Multiple Regression are presented in figure(s) 44-48 below:

1. Multiple Linear Regression:

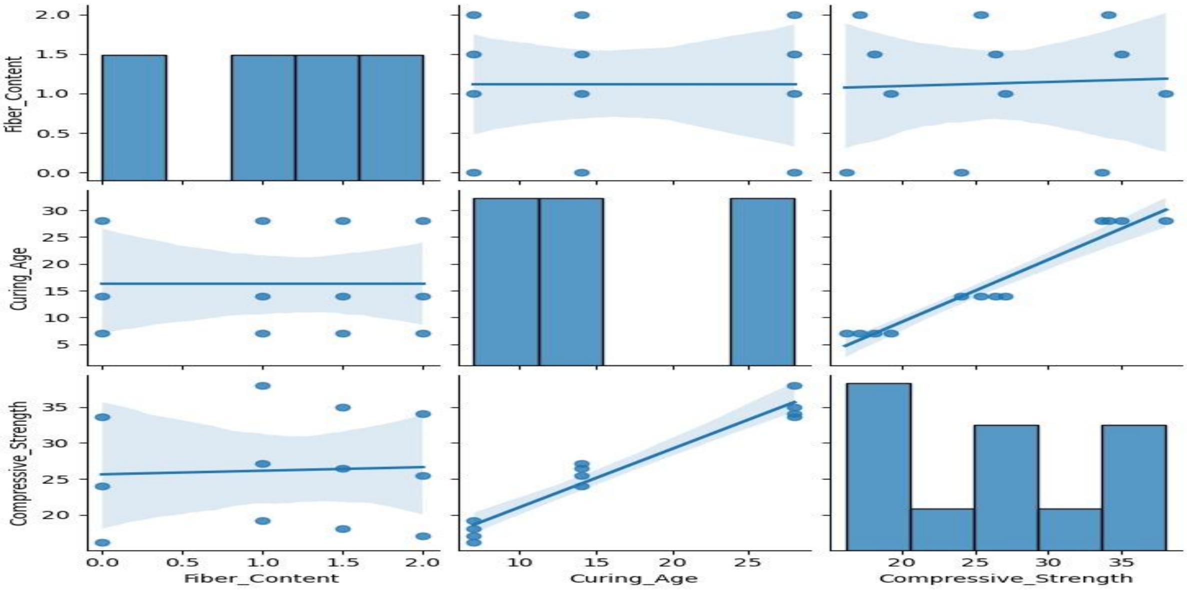


Figure 44: *Correlation Matrix of Compressive Strength with varying Modified Jute Using a Multiple Regression Model*

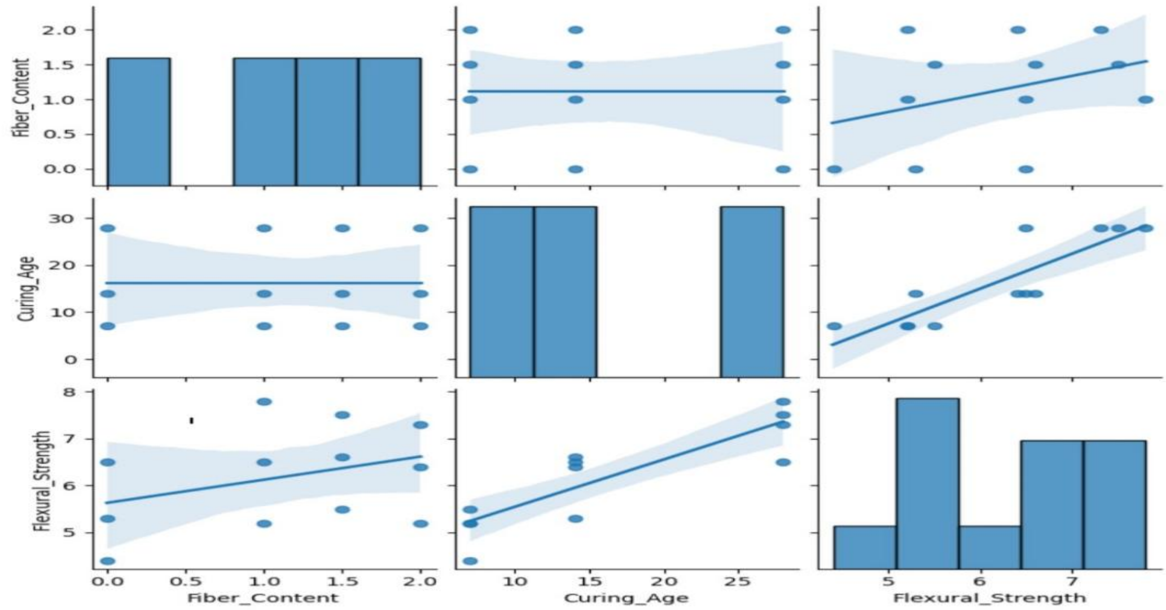


Figure 45: *Correlation Matrix of Flexural Strength with varying Modified Jute Using Multiple Regression Model*

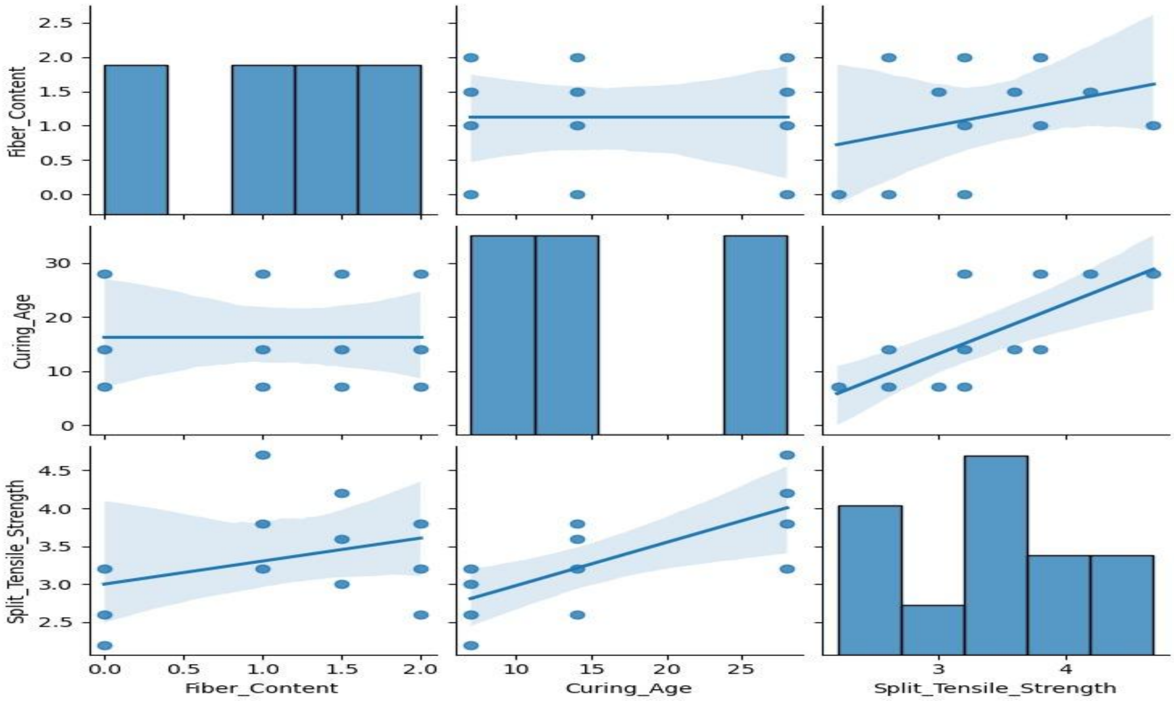


Figure 46: *Correlation Matrix of Split Tensile with varying Modified Jute Using a Multiple Regression Model*

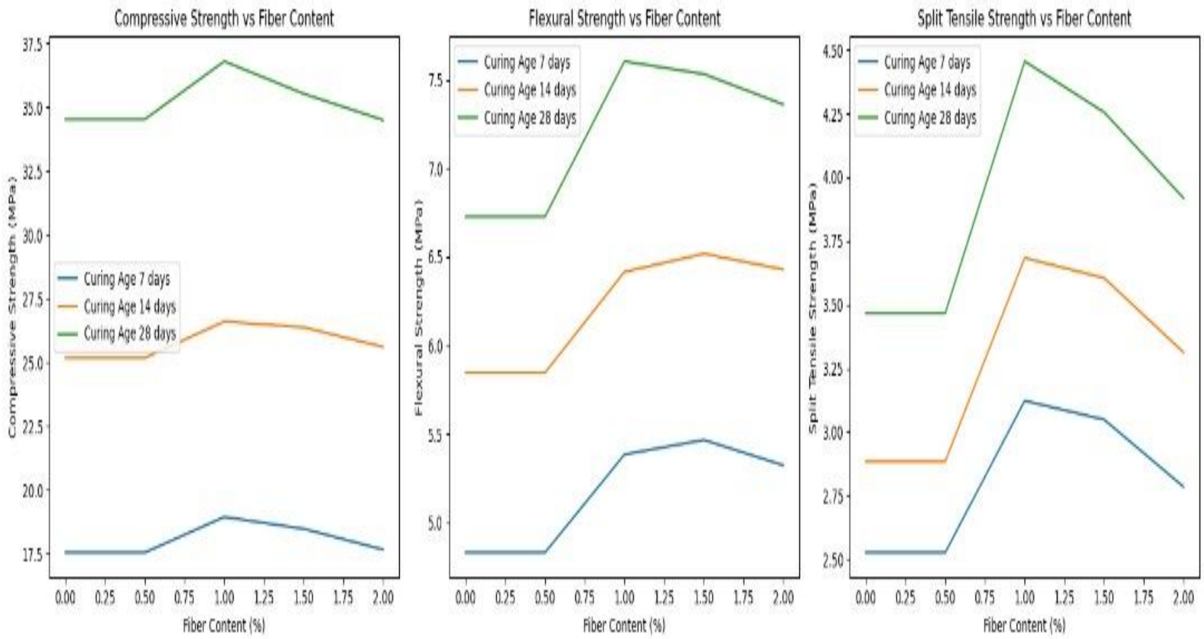


Figure 47: *Correlation Matrix of C.S, F.S & SPT with varying Modified Jute Using a Multiple Regression Model*

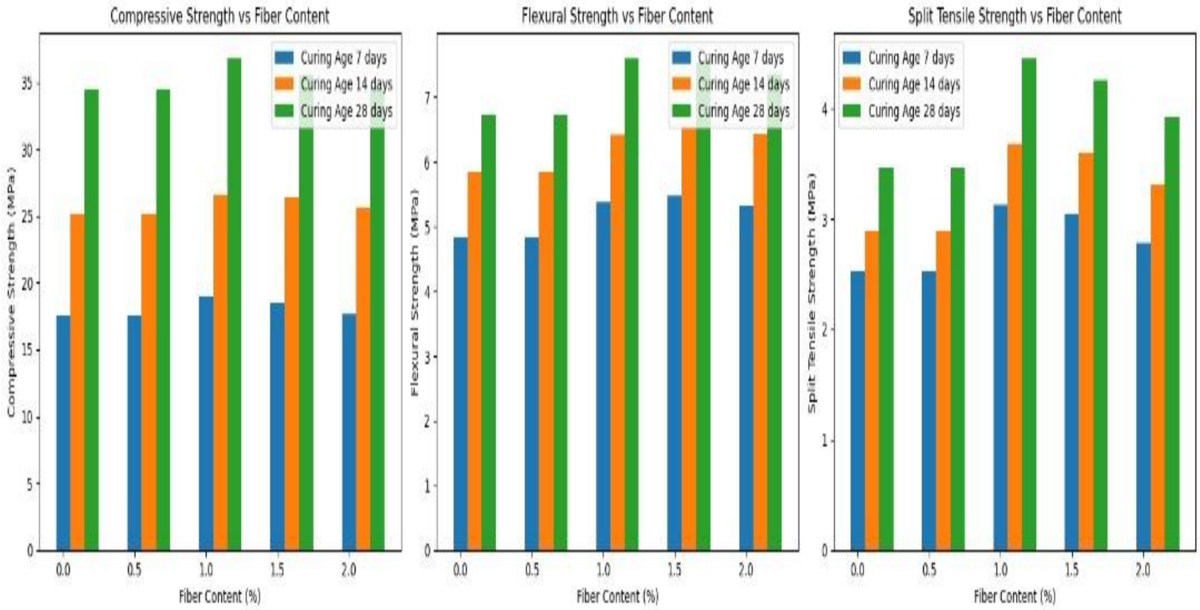


Figure 48: *Relationship of C.S, F.S, and SPT with varying Modified Jute Using a Multiple Regression Model*

2. Visualization of Random Forest Regression

This simulation is also used to predict Compressive, Flexural and split Tensile Strengths based on curing age and fiber contents and the results visualizes the actual vs predicted results for each mechanical property. The actual vs predicted results using Random Forest are shown in figure 49.

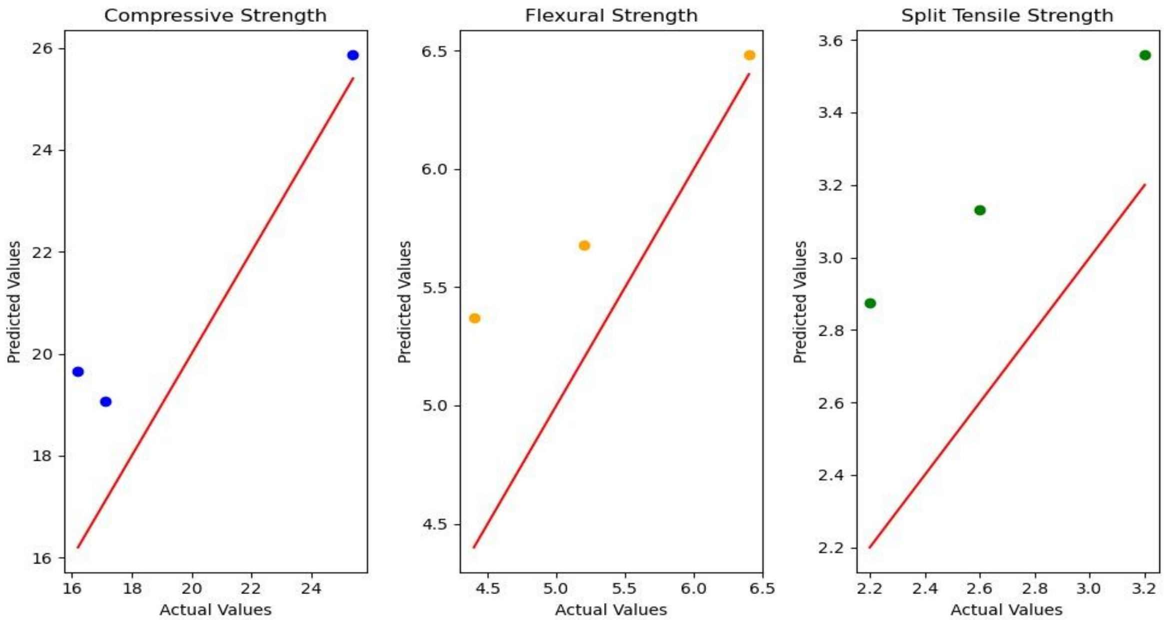


Figure 49: *The Actual vs predicted Random Forest Results for C.S, F.S & S.P.T*

X. Discussion of Results:

1. Experimental Results:

The data presented in the tables offer a comparative analysis of the ***specific gravity and water absorption*** properties of ***coarse aggregates, fine aggregates, and treated jute fiber***. For ***coarse aggregates,*** the weights of both the empty basket in water and the saturated surface-dry aggregates show minimal variation across trials, reflecting consistent testing conditions. The oven-dried aggregate weights are also stable, which indicates that the aggregates were properly dried before testing. The calculated specific gravity values (2.71, 2.69, and 2.70) yield an average of 2.70, signifying that the aggregates have a good balance of density relative to water. Similarly, the apparent specific gravity, which takes into account the internal porosity of the aggregates, averages to 2.73. These values suggest that the aggregates have minimal porosity, which is beneficial for structural applications. Water absorption values are consistently low, averaging 0.30%, indicating that the aggregates absorb very little moisture, which is a desirable characteristic for maintaining concrete strength and durability.

For ***fine aggregates***, the weights of the saturated surface-dry samples, the pycnometer with the sample and water, and the oven-dried samples are also consistent across trials, ensuring the accuracy of the measurements. The specific gravity values (2.68, 2.62, and 2.72) average to 2.67, slightly lower than that of the coarse aggregates. The apparent specific gravity is higher, with an average of 2.82, reflecting the presence of internal pores within the fine aggregates. Fine aggregates also exhibit higher water absorption, with an average of 1.93%, due to their larger surface area compared to coarse aggregates. This higher absorption needs to be considered when adjusting water content in concrete mixes to maintain workability and strength.

In the case of ***treated jute fiber***, the weights of the saturated surface-dry samples and the oven-dried samples display more variability compared to the aggregates, likely due to differences in fiber moisture content after drying. The specific gravity values (0.97, 1.19, and 1.03) average to 1.06, which is much lower than that of the aggregates. This reflects the lightweight and porous nature of jute fibers. The apparent specific gravity, averaging 1.67, also supports the conclusion that the fibers are less dense and more porous than both coarse and fine aggregates. Notably, the water absorption of treated jute fiber is significantly higher, averaging 30.93%. This indicates that jute fiber retains a large amount of moisture, which could impact concrete performance, particularly in terms of workability and the water-cement ratio. In brief, the ***Coarse and fine aggregates*** exhibit relatively high specific gravity and low water absorption, making them suitable for maintaining the strength and stability of concrete. In contrast, ***treated jute fiber*** is much lighter and more absorbent, with a lower specific gravity and significantly higher water absorption. This difference highlights the need for careful adjustment in concrete mix designs when incorporating jute fiber, as its properties can influence the mix's workability and moisture balance.

The graph representing the results of ***sieve analysis***, commonly used in materials testing to assess the particle size distribution of aggregates or other granular materials. The horizontal axis displays **sieve size** in millimeters on a **logarithmic scale**, while the vertical axis shows the **percentage passing**, which indicates the cumulative percentage of material that has passed through each sieve. In the **Logarithmic Sieve Size Axis,** the x-axis is plotted logarithmically, which is particularly useful in sieve analysis due to the wide range of particle sizes being evaluated, from fine particles to coarse aggregates. A logarithmic scale ensures that the smaller sieve sizes are appropriately spaced, providing better visibility and differentiation between the finer sieves (e.g., 0.075 mm, 0.15 mm). Larger sieve sizes are also spaced out effectively, making it easier to analyze both small and large particle distributions in a single graph.

Then the **Percentage Passing** is the y-axis, showing the percentage passing, represents the cumulative percentage of material that has passed through each sieve. For example, at the sieve size of 10 mm, 100% of the material passes through, meaning all the material is smaller than 10 mm. As the sieve size decreases, the percentage passing reduces, showing that progressively less material passes through the smaller sieves. The **Shape of the Curve,** is the overall shape of the curve which indicates how the material is distributed across different particle sizes. A steep curve, as seen in parts of your graph, suggests that a large percentage of material is concentrated within a particular size range (e.g., between 0.6 mm and 2.36 mm). Conversely, a flatter portion of the curve, like at the lower sieve sizes, indicates that the material is more uniformly distributed across those particle sizes. Than **Grading and Material Characteristics,** occurs when the slope and shape of the graph provide insight into the **grading** of the material. A smooth, gradual curve typically suggests well-graded material, with a good distribution of particle sizes, which is ideal for applications such as concrete production. On the other hand, sharp transitions could indicate poorly graded material with a significant portion of the particles clustered around certain sizes, which might lead to issues in construction or processing applications. This analysis helps determine if the material meets specific **grading requirements**, influencing decisions about its use in construction, such as for creating durable concrete mixtures or for effective compaction in road construction.

The Slump / Workability Tests of **0% Treated Jute Fiber** was found to be **(75mm).** This is normal workability. It is a standard slump value, indicating good workability and ease of placement for the concrete without fiber reinforcement. The second is **the 1% Treated Jute Fiber** was found to be **(0.12mm),** which was significantly reduced workability, the slump is extremely low, suggesting that the introduction of 1% fiber has greatly reduced the flow of the concrete, making it much stiffer. Then **the 1.5% Treated Jute Fiber** was **(0.7mm),** and is called the severely reduced workability and the concrete has become highly stiff with an almost non-existent slump, making it difficult to work with or place properly. Lastly, was **the 2% Treated Jute Fiber** with **(0.3mm),** the reduced workability, there is a slight improvement in slump compared to the 1.5% sample, but with the concrete still being very stiff. As per fiber content increases, the workability decreases.

The compressive strength of concrete increases over time, and the addition of jute fibers can slightly improve this strength, particularly at lower percentages like 1%. At 28 days, the optimal compressive strength is recorded at 33.6 MPa. The 1% fiber content shows slight improvements at 7 and 14 days compared to 0%, with the peak performance at 28 days at 38.0 MPa, suggesting a balance between fiber reinforcement and strength. At 1.5% fiber content, there is a slight decrease in compressive strength at 7 and 14 days due to reduced workability and fiber interference, with a maximum strength of 35.0 MPa at 28 days. At 2% fiber content, a noticeable reduction in strength occurs across all time intervals, with the lowest 28-day strength recorded at 34.1 MPa, indicating diminishing returns as fiber content increases. Generally, increasing fiber content beyond an optimal point, such as 1%, leads to reduced compressive strength due to issues like poor workability, fiber clumping, and difficulties in compaction. Proper compaction, curing, and workability are essential for achieving good results. The study highlights that while treated jute fibers can enhance concrete, care must be taken to ensure even fiber distribution and effective matrix compaction. Contradictory findings exist between studies on treated and untreated jute fibers, but this experiment shows that 1% treated jute fiber provides the best balance for strength improvement.

The research shows that flexural strength improves or stabilizes with increasing fiber content and curing age. For grade 30 concrete, 1% to 1.5% treated jute fiber content offers the best balance between material properties and strength, while 2% shows diminishing returns. The control sample (0% fiber) serves as a base with no fiber reinforcement, recording 6.5 MPa at 28 days due to hydration alone. At 1% fiber content, significant improvements in flexural strength occur at 7, 14, and 28 days, peaking at 7.8 MPa on the 28th day. This suggests that 1% fiber is optimal for flexural performance. At 1.5%, strength continues to improve but begins to plateau, showing only slight gains over 1%, with a final strength of 7.5 MPa at 28 days. At 2%, flexural strength plateaus, with a lower strength of 7.3 MPa at 28 days, indicating diminishing effectiveness due to excessive fiber content. Overall, 1% treated jute fiber provides the best enhancement in flexural strength, with 1.5% offering slight additional benefits, while 2% leads to reduced workability and compaction issues. Treated jute fiber is recommended for improving flexural strength, but excessive fiber content may negatively impact concrete performance.

The Split Tensile Strength Tests results shows that the Treated Jute Fibers significantly enhanced split tensile strength, especially at 1% fiber content. The strength improves with curing time, peaking at 28 days for each fiber percentage, with 1% content being the most effective across all curing periods. Firstly, In the **0% Fibers (Control),** the standard concrete without fibers shows a typical increase in split tensile strength with curing time, reaching in average of 3.2 MPa at 28 days. Secondly, **1% Treated Fibers** shows the highest split tensile strength is observed at 1% fiber content, with the strength increasing progressively from 3.2MPa at 7 days to 4.7 at 28 days. Than the **1.5% Treated Fibers** shows the strength increases with curing time, peaking at 4.2 MPa at 28 days but is lower than the 1% fiber content results. And lastly, **2% Treated Fibers:** The strength is slightly lower across all curing times, reaching 3.8 MPa at 28 days, due to the negative impact of excessive fiber content on matrix continuity.

2. **Machine Learning (ML) and Simulation:**

i. Multiple Linear Regression Analysis:

The Multiple Regression Analysis, is used to understand the relationship between one dependent variable and multiple independent variables. In this case, compressive strength is predicted as the dependent variables, i.e., ***Fiber Content*** is the Percentage of jute fibers used (0%, 1%, 1.5 and 2%). Then the ***Curing Age*** means the Number of curing days (7, 14 and 28 days). Additionally, an interaction term is included (Fiber - Content X Curing - Age) to account for the combined effect of these variables. Then ***Compressive Strength* = β0 + β1; Where, β1 + β2 and β3** are the coefficients that represent the contribution of each predictor to the compressive strength.

Therefore, the ***Multiple Regression Analysis*** for ***Compressive strength*** is done with the OLS regression model for predicting compressive strength demonstrates a strong overall fit, explaining 94.8% of the variance in compressive strength, with an R-squared value of 0.948 and an adjusted R-squared of 0.929. The model is statistically significant overall, as indicated by the F-statistic of 48.72 and a highly significant p-value. This suggests that the combination of fiber content, curing age, and their interaction contributes to the prediction of compressive strength. However, when looking at individual predictors, none achieved statistical significance at the 5% level. Fiber content has a positive effect on compressive strength, with a coefficient of 0.82, and curing age also shows a positive effect with a coefficient of 0.83. Despite these positive trends, both predictors have high p-values, indicating that their effects are not statistically significant. The interaction term between fiber content and curing age shows a slight negative impact, but this too is not significant. The model diagnostics indicate no major issues, with acceptable values for the Durbin-Watson statistic, normality tests, skew, and kurtosis. While the model explains a large portion of the variation in compressive strength, the lack of significance in individual predictors suggests that further data or model refinement may be necessary to draw stronger conclusions about the specific effects of fiber content and curing age on compressive strength.

The ***Multiple Regression Analysis*** for ***Flexural Strength*** is also done wit the Ordinary Least Squares (OLS) regression analysis for flexural strength reveals a model with a high R-squared value of 0.879, indicating that approximately 87.9% of the variability in flexural strength is explained by the model. The adjusted R-squared value of 0.834 further suggests a strong fit after accounting for the number of predictors. The F-statistic of 19.37, with a p-value of 0.000502, confirms that the model is statistically significant. The coefficient for fiber content is 0.5514, though it is not statistically significant (p = 0.162), implying that fiber content may have a minor or uncertain impact on flexural strength. In contrast, curing age shows a significant positive effect on flexural strength with a coefficient of 0.1049 (p = 0.004), indicating that each additional unit of curing age increases flexural strength. The interaction term between fiber content and curing age has a coefficient of -0.0037 with a p-value of 0.854, suggesting that the combined effect of these variables on flexural strength is minimal.

Lastly, the ***Multiple Regression Analysis*** for ***Split Tensile strength***, the OLS regression model has a lower R-squared value of 0.632, meaning it explains 63.2% of the variability in split tensile strength. The adjusted R-squared of 0.493 indicates that the model's explanatory power is somewhat reduced after accounting for the number of predictors. The F-statistic of 4.570 with a p-value of 0.0381 shows that the model is statistically significant. The coefficient for fiber content is 0.2486, but it is not statistically significant (p = 0.572), suggesting that fiber content does not have a strong influence on split tensile strength. Curing age also has a coefficient of 0.0531, which is marginally significant (p = 0.122), indicating a possible but not strong effect on split tensile strength. The interaction term between fiber content and curing age has a coefficient of 0.0033 and a p-value of 0.888, indicating a negligible combined effect on split tensile strength.

In Comparison between the three, the regression results show that the models for Compressive and Flexural Strength are strong, with high R Squared values (0.948 and 0.879, respectively) and significant predictors. Curing Age significantly affects both, but Fiber Content and the interaction term are not significant. The Split Tensile Strength model is weaker (R Squared = 0.632) with less significant predictors, indicating lower explanatory power compared to the other two models.

ii. **Random Forest Regression Model - Machine Learning**

Random Forex, a machine learning and ensemble learning method, creates multiple decision trees during training and merges them by averaging predictions to enhance accuracy and prevent overfitting. This approach is effective in regression tasks, such as predicting concrete strength based on features like curing age and fiber content. In this project, Random Forex Regression was selected to model the relationship between curing age, fiber percentages, and mechanical properties of concrete, such as compressive, flexural, and split tensile strengths. The model was used to predict the mechanical strengths of concrete reinforced with modified jute fibers. Visual assessments were made using actual vs. predicted value plots.

For compressive strength, the blue plot revealed some variability, with several data points deviating from the ideal prediction line, especially in the range of 18 to 20 MPa. This indicates that while the model captures the general trend, it struggles with perfect accuracy for certain data points. In contrast, the orange plot for flexural strength shows a strong correlation between predicted and actual values, as most data points lie near the ideal prediction line, suggesting Random Forex is a good fit for predicting flexural strength. However, for split tensile strength (green plot), the model exhibits more variability, particularly at lower strength values, where it tends to under-predict, suggesting that the model may not generalize well in the lower ranges of tensile strength.

Overall, the Random Forex model performs best for predicting flexural strength, where the predictions closely align with actual values. For compressive strength, the model shows reasonable accuracy with slight deviations, while split tensile strength predictions display the most noticeable errors, especially at lower levels. This variation in model performance might be due to the complex interactions between curing age, fiber content, and tensile strength, which may require further refinement of the model's features to improve accuracy.

3. Interpretation of ANOVA Results and Hypothesis:

In each **ANOVA** Tables, the ***Sum-Sq*** is the Sum of squares due to each source of variation (fiber content and residual), secondly the ***df*** means Degrees of freedom. Then ***F*** is the **F-statistic,** which tests the hypothesis that the means are equal. Lastly ***PR(>F)*** which means the P-value associated with the F-static. Then, for the Hypothesis Testing**,** If the ***p-value*** is less than the significance level **(commonly 0.05),** just reject the null hypothesis, indicating a significant effect of fiber content on the respective strength property. But If the ***p-value*** is greater than the significance level**,** do not reject the null hypothesis, indicating no significance effect.

Therefore**,** for the **Compressive Strength (Ho1),** the ***F-Value*** is equal to ***0.086847*,** then the ***P-Value*** is found to be ***0.965281***. then here, the ***p-value*** is much higher than ***0.05***, meaning we fail to reject **Ho1**. These means, the incorporation of modified jute fibers does **not significantly reduce** the compressive strength of concrete.

Secondly is the **Flexural Strength (Ho2)** with ***F-Value*** **of** ***0.691995*** and ***P-Value*** of ***0.582174.*** Therefore, the ***p-value*** is greater than ***0.05***, so we also fail to reject **Ho2**. This indicates that modified jute fibers do **not significantly hinder** the flexural strength of concrete.

Lastly, for the **Split Tensile Strength (Ho3)** the ***F-Value*** is ***2.213823*** and ***P-Value*** is ***0.164077.*** Therefore, the ***F-value*** for split tensile strength is relatively higher, the p-value which is still above ***0.05***. which means, we also fail to reject **Ho3**, suggesting that the use of jute fibers does **not significantly reduce** the split tensile strength.

The **Ho1, Ho2, and Ho3** are all supported by the results, as the **p-values** for compressive, flexural, and split tensile strengths are all greater than **0.05**. This means the incorporation of modified jute fibers does not have a statistically significant reduction or weakness on these mechanical properties of concrete based on the data.

XI. Summary of Findings:

This project explores the enhancement of concrete performance using chemically modified jute fiber as a sustainable reinforcement. The jute fibers were treated with sodium hydroxide (NaOH) to improve their bonding with the cement matrix and were cut to a uniform length of 20 mm. Various percentages of fiber (0%, 1%, 1.5%, and 2%) were added to M30-grade concrete, and the impact on its mechanical properties was thoroughly tested. Material testing was performed to assess the properties of the aggregates and jute fibers, including specific gravity, sieve analysis, and water absorption. The treated jute fibers demonstrated higher water absorption than aggregates, which affected the workability of fresh concrete, as revealed by slump tests showing reduced slump with increasing fiber content.

The Mechanical property tests, such as compressive, flexural, and split tensile strength evaluations, were conducted on the hardened concrete. The results showed that the inclusion of jute fibers had the most significant positive effect on flexural and split tensile strength, particularly at 1% fiber content, while the compressive strength remained largely unaffected.

The hypothesis testing in this study aimed to determine whether the incorporation of modified jute fibers significantly affects the mechanical properties of concrete, including compressive, flexural, and split tensile strengths. The hypotheses tested were as follows:

- Ho1: The incorporation of modified jute fibers does not significantly decrease the compressive strength of concrete.
- Ho2: The inclusion of modified jute fibers does not significantly enhance the flexural strength of concrete.
- Ho3: The use of jute fibers does not significantly impact the split tensile strength of concrete.

Using ANOVA (Analysis of Variance), the p-values for the compressive, flexural, and split tensile strength were greater than 0.05, indicating that the null hypotheses could not be rejected. This suggests that while jute fiber inclusion influences certain properties, such as improving flexural and tensile strengths, the changes were not statistically significant enough to reject the null hypotheses at the 0.05 significance level. Thus, jute fibers enhance concrete performance, particularly in flexural and tensile strength, without significantly compromising compressive strength. In addition, machine learning models, including multiple linear regression and Random Forest regression, were applied to predict concrete performance based on fiber content and curing age. These models successfully predicted compressive and flexural strengths with high accuracy, though predictions for split tensile strength were less precise.

In a nut shell, this project indicates that, the modified jute fibers can improve certain mechanical properties of concrete, particularly tensile and flexural strengths, while maintaining compressive strength. The successful application of machine learning in predicting concrete behavior further highlights its potential for optimizing concrete mix design in future research.

XII. Conclusion:

The experimental results highlight the impact of modified jute fibers on concrete performance, particularly in terms of compressive, split tensile and flexural strengths. The material tests, including specific gravity, sieve analysis, and water absorption, showed that both coarse and fine aggregates possessed desirable properties for concrete applications, such as low water absorption and high density. However, treated jute fiber exhibited significantly higher water absorption, which could influence the water-cement ratio and workability of the concrete mix. Fresh concrete tests, particularly the slump test, revealed that increasing fiber content reduced workability, with a slump of 75 mm for 0% fiber and significantly lower values for higher fiber percentages. Mechanical tests demonstrated that the inclusion of 1% jute fiber resulted in optimal flexural and split tensile strength, while compressive strength remained largely unaffected by fiber content.

The machine learning models used in the study provided reliable predictions of compressive and flexural strengths, but the split tensile strength model showed less accuracy. Multiple linear regression and Random Forest regression effectively modeled the influence of curing age and fiber content on the mechanical properties of concrete. However, further refinement of the models, particularly for split tensile strength, may be necessary.

The hypothesis testing performed using ANOVA revealed that modified jute fibers do not significantly decrease compressive, flexural, or split tensile strengths at a significance level of 0.05. Despite minor variations in individual strength properties, the p-values for all mechanical properties were greater than 0.05, leading to the conclusion that the null hypotheses could not be rejected. These findings suggest that the incorporation of modified jute fibers does not detrimentally impact the mechanical performance of concrete, while providing benefits to flexural and tensile strength, particularly at 1% fiber content

XIII. Recommendations:

Based on the findings of this study, several recommendations can be made for future research and practical applications:

1. The use of 1% modified jute fiber is recommended for improving the flexural and split tensile strengths of concrete without significantly affecting compressive strength.

2. Since the addition of jute fibers reduces the workability of fresh concrete, the use of superplasticizers or other additives should be considered to maintain desired workability levels, particularly for higher fiber content mixes.

3. Further and more Machine Learning models should be applied in predicting the mechanical properties of fiber-reinforced concrete. especially for refining the split tensile strength, and explore other algorithms to improve prediction accuracy.

4. More long-term durability studies are needed to evaluate the performance of jute fiber-reinforced concrete under varying environmental conditions, such as freeze-thaw cycles and chemical exposure.

5. The use of natural fibers like jute promotes sustainability. Therefore, broader studies should assess the cost-effectiveness and environmental benefits of jute fiber-reinforced concrete in large-scale applications.

5. Declaration of Funding:

Most of the materials used in the experimental-lab work of this study, were provided by the Management of Mewar University under the Civil Engineering Department. But the research did not receive any specific funding or grant from any agency in the public, private and non-profit sectors.

References:

[1]. Abdullah, A., Mansur, A., Hossain, A., Anisha, A., Tahmid, A., & Chowdhury, S. (2022). PERFORMANCE OF JUTE FIBER REINFORCED CONCRETE IN THE CONTEXT OF BANGLADESH. *International Journal of Civil Engineering*, *34*, 25–35. https://doi.org/10.11113/mjce.v34.18724

[2]. Ahmad, J., Zaid, O., Siddique, M. S., Aslam, F., Alabduljabbar, H., & Khedher, K. (2021). Mechanical and durability characteristics of sustainable coconut fibers reinforced concrete with incorporation of marble powder. *Materials Research Express*, 75505.

[3]. Ahmed, S., & Islam, M. (2018). Influence of jute fiber on concrete properties. *Construction and Building Materials*, *189*, 768–776. https://doi.org/10.1016/j.conbuildmat.2018.09.048

[4]. Ali, Y., Sabeeh, N., Yass, M., Ahmed, A., & Salih, E. (2019). Concrete Beams Strengthened with Jute Fibers. *Civil Engineering Journal*, *5*, 767–776. https://doi.org/10.28991/cej-2019-03091286

[5]. Aluko, O., Yatim, J., Ab Kadir, M. A., & Yahya, K. (2020). A review of properties of bio-fibrous concrete exposed to elevated temperatures. *Construction and Building Materials*, *260*, 119671. https://doi.org/10.1016/j.conbuildmat.2020.119671

[6]. Asaduzzaman, S., & Islam, G. M. (2023). Using Jute Fiber to Improve Fresh and Hardened Properties of Concrete. *Journal of Natural Fibers*, *20*. https://doi.org/10.1080/15440478.2023.2204452

[7]. Datta, E., Rahman, S., & Hossain, M. (2016). *Different Approaches to Modify the Properties of Jute Fiber: A Review*. *5*, 24–27.

[8]. Elsaid, A., Dawood, M., Seracino, R., & Bobko, C. (2011). Mechanical properties of kenaf fiber reinforced concrete. *Construction and Building Materials*, *25*, 1991–2001. https://doi.org/10.1016/j.conbuildmat.2010.11.052

[9]. Hasan, K. M. F., Horváth, P., & Alpar, T. (2020). Potential Natural Fiber Polymeric Nanobiocomposites: A Review. *Polymers*, *12*, 1072. https://doi.org/10.3390/polym12051072
[10]. IS Code, & Jangeed, D. (2019). *IS Code 10262- 2019 Concrete Mix Design a New Code without watermark*.
[11]. Islam, S., & Hussain, R. (2012). Fiber-reinforced concrete incorporating locally available natural fibers in normal- and high-strength concrete and a performance analysis with steel fiber-reinforced composite concrete. *Journal of Composite Materials - J COMPOS MATER*, *46*, 111–122. https://doi.org/10.1177/0021998311410492
[12]. Kabir, M. M., ISLAM, M., & WANG, H. (2013). Mechanical and Thermal Properties of Jute Fibre Reinforced Composites. *Journal of Multifunctional Composites*, *1*, 71–76. https://doi.org/10.12783/issn.2168-4286/1.1/Islam
[13]. Khan, M., Shafiq, N., Waqar, A., Radu, D., Cismaș, C., Imran, M., Almujibah, H., & Benjeddou, O. (2023). Effects of Jute Fiber on Fresh and Hardened Characteristics of Concrete with Environmental Assessment. *Buildings*, *13*, 1691. https://doi.org/10.3390/buildings13071691
[14]. Kirupairaja, T., Yogananth, Y., Sangeeth, P., Coonghe, J., & Sathiparan, N. (2019). Strength and Durability Characteristics of Coconut Fibre Reinforced Earth Cement Blocks. *Journal of Natural Fibers*, *18*, 1–16. https://doi.org/10.1080/15440478.2019.1652220
[15]. Lasiyal, N., Balot, N. K., Sharma, P., Falwaria, N., & Meena, P. K. (2016). Experimental Study of Concrete Additive Jute as Geotextile Material. *International Journal of Engineering Research & Technology (IJERT) NCACE - 2016 Conference Proceedings*, *4*(23). https://doi.org/DOI : 10.17577/IJERTCONV4IS23054
[16]. Mai, H.-V., Nguyen, H. M., Trinh, S., & Ly, H.-B. (2023). Optimization of machine learning models for predicting the compressive strength of fiber-reinforced self-compacting concrete. *Frontiers of Structural and Civil Engineering*. https://doi.org/10.1007/s11709-022-0901-6
[17]. Mohammadi, Y., Singh, S. P., & Kaushik, S. (2008). Properties of steel fibrous concrete containing mixed fibres in fresh and hardened state. *Construction and Building Materials*, *22*, 956–965. https://doi.org/10.1016/j.conbuildmat.2006.12.004
[18]. N. Nageswari & Dr. R. Divahar. (2022). Experimental Investigation on Hybrid Fibre Reinforced Concrete by Partial Replacement of M-Sand with Fine Aggregate. *International Journal of Latest Engineering Research and Applications (IJLERA)*, *07*(02), 37–43.
[19]. Pantamanatsopa, P., Ariyawiriyanan, W., Meekeaw, T., Suthamyong, R., Arrub, K., & Hamada, H. (2014). Effect of Modified Jute Fiber on Mechanical Properties of Green Rubber Composite. *Energy Procedia*, *56*. https://doi.org/10.1016/j.egypro.2014.07.203
[20]. Raju, M. R., Rahman, M. M., Islam, M. M., Hasan, N., Md Mehedi, H., Sharmily, T., & Hosen, M. (2024). A Comparative Analysis of Machine Learning Approaches for Evaluating the Compressive Strength of Pozzolanic Concrete. *IUBAT Review*, *7*, 90–122. https://doi.org/10.3329/iubatr.v7i1.74329
[21]. Rashid, K., Haq, E. U., Kamran, M. S., Munir, N., Shahid, A., & Hanif, I. (2019). Experimental and finite element analysis on thermal conductivity of burnt clay bricks reinforced with fibers. *Construction and Building Materials*, *221*, 190–199. https://doi.org/10.1016/j.conbuildmat.2019.06.055
[22]. Sahu, P., & Tudu, C. (2020). Effect of Jute Fibre Orientation and Percentage on Strength of Jute Fibre Reinforced Concrete. *International Journal of Engineering and Advanced Technology*, *9*, 1767–1770. https://doi.org/10.35940/ijeat.C4708.029320
[23]. Sultana, N., Hossain, S. M., Alam, M., Hashish, M., & Islam, M. (2020). An experimental investigation and modeling approach of response surface methodology coupled with crow search algorithm for optimizing the properties of jute fiber reinforced concrete. *Construction and Building Materials*, *243*. https://doi.org/10.1016/j.conbuildmat.2020.118216
[24]. Vishwanath, K., Shashikumar, L., Head, & Professor, A. (2019). *PERFORMANCE EVALUATION AND STRENGTH AUGMENTATION OF CEMENT MORTAR EINFORCED WITH TREATED JUTE FIBRE: A REVIEW*.
[25]. Yan, L. (2013). Compressive and flexural behaviour and theoretical analysis of flax fibre reinforced polymer tube encased coir fibre reinforced concrete composite. *Materials and Design*, *52*, 801–811. https://doi.org/10.1016/j.matdes.2013.06.018
[26]. Yang, J., Du, Q., & Bao, Y.-W. (2011). Concrete With Recycled Concrete Aggregate and Crushed Clay Bricks. *Construction and Building Materials*, *25*, 1935–1945. https://doi.org/10.1016/j.conbuildmat.2010.11.063
[27]. Yazıcı, Ş., İnan, G., & Tabak, V. (2007). Effect of aspect ratio and volume fraction of steel fiber on the mechanical properties of SFRC. *Construction and Building Materials - CONSTR BUILD MATER*, *21*, 1250–1253. https://doi.org/10.1016/j.conbuildmat.2006.05.025
[28]. Zakaria, M. (2018). A Comparative Study of the Mechanical Properties of Jute Fiber and Yarn Reinforced Concrete Composites. *Journal of Natural Fibers*, *17*. https://doi.org/10.1080/15440478.2018.1525465
[29]. Zhu, W. (2020). *Permeation properties of self-compaction concrete* (pp. 117–130). https://doi.org/10.1016/B978-0-12-817369-5.00005-2