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Laboratory-Based and Data-Driven Learning of Concrete Enhanced with Modified Jute Fiber Reinforcement for Sustainable Flexural Prediction

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Abstract: In this work, only 36 concrete beams were prepared, to study the performance of concrete reinforced with modified jute fiber, which focus on its mechanical properties preferably flexural strength 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 flexural strength Tests. The results were quantitatively analyzed, the hypothesis test was performed using ANOVA revealed that modified jute fibers do not significantly decrease flexural 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 0.879 for flexural strength. The results suggest that chemically modified jute fibers enhance flexural properties, and machine learning can effectively model these improvements.

Keywords: *Modified Jute Fiber, Reinforced Concrete, Machine Learning, Random Forest, Multiple Linear Regression, Flexural Strength.*

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I. INTRODUCTION

➢ *Research Background*

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

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(Ramaswamy, 1983), A high tensile strength is found, from 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), stated a marginal loss when the fibers were embedded in cement concrete. (Zakaria, 2018), also reported improved compressive, tensile and flexural strength when concrete is incorporated with jute and yarn fibers in concrete. (Ahmed & Islam, 2018), Addition of small closely-spaced, uniformly distributed fibers. control cracks due to plastic shrinkage and to drying shrinkage, substantially increase static and dynamic properties. Fibers enhances concrete self-weight and could induce a balling effect during mixing, reducing workability.

(Aluko et al., 2020), and (Elsaid et al., 2011), reported that, the bark of the Jute plant is the source of fibers. The plant could be up to around 2.5m tall, with a stem diameter of around 25 mm at the bottom. Then the matured plants are wrapped into bundles and submerged underwater, then 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).

The study is about Jute Fiber Modification firstly, as addition to the existing reinforcement technique where by the fiber is treated with Alkali Sodium, called the sulphonation method. 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. The modified jute fiber significantly improved the mechanical properties of concrete as compared to plain or unmodified fibers, (Datta et al., 2016), (Ubayi et al., 2024) and (Asaduzzaman & Islam, 2023). The modification techniques, such as chemical treatment or hybridization with other fibers, enhances the properties of jute fiber, (N. Nageswari & Dr. R. Divahar, 2022) and (Rashid et al., 2019).

In this study, 36 beams were prepared, with varying fiber contents of 0%, 1%,1.2% and 2% with varying curing times, followed by mechanical tests which tested flexural strengths. The results adopted quantitative research method, including statistical analysis such as *graphs and ANOVA*, to interpret the experimental data. Then, the *Linear Regression and Random Forest* were also implemented as the machine learning algorithms used in the study, to predict the concrete strength based on their fiber percentages and curing times. In the study, 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. In a nut shell, the study highlighted not everyone in developing countries like Nigeria can afford most of the Artificial Fibers we nowadays have, but the Natural fibers are widely available, low on cost and strength enough for construction purposes, therefore, these Natural fibers are considered a sustainable solution to reinforced concrete materials.

➢ *Research Significant*

There was always continuous need for an innovative and affordable materials as a substitute of the expensive materials and concrete sustainability. The Study proposes the *"Laboratory-based and Data-Driven Learning of Concrete Enhanced with Modified Jute Fiber Reinforcement for Sustainable Flexural Prediction,"* which led to a significant Enhancement of Mechanical Properties of Concrete, it is also significant to the Economic Benefit, Reducing Cost of Material and Support Local Technologies, It gives contribution to Research and gives insights on substitute reinforcement of concrete, the study Promote Innovation in Material Science and analysis through Machine Learning Algorithms.

II. LITERATURE REVIEW

There are so many relevant topics which were read from different journals but few among the papers were summarized on Jute Fibers. Some of the articles were on Machine learning application on concrete performance. The other remaining papers were read, understood and further used as references in this work.

A. Studies on Treated Jute Fibers:

The following 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.

- There was a study titled: *"Experimental Study of Concrete Additive Jute as Geotextile Material"*, Published in the International Journal of Engineering Research & Technology (IJERT), Volume 4, Issue 23. The study highlights 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 showed 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, (Lasiyal et al., 2016).

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- Another paper was also written on *"Using Jute Fiber to Improve Fresh and Hardened Properties of Concrete".* This was 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, (Asaduzzaman & Islam, 2023).
- The Journal of Multifunctional Composites (2013), revealed the *"Mechanical and Thermal Properties of Jute Fiber Reinforced Composites."* The study explores 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, (Kabir et al., 2013).
- 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 by Elsevier - Energy Procedia, 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, (Pantamanatsopa et al., 2014).

B. Machine Learning Application on Concrete Performance:

The following 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.

- A publication 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"*, which was 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, (Sultana et al., 2020).
- An *"Optimization of machine learning models for predicting the compressive strength of fiber-reinforced self-compacting concrete"* was published in the journal of "Frontiers of Structural and Civil Engineering". The study 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, (Mai et al., 2023).
- *"A Comparative Analysis of Machine Learning Approaches for Evaluating the Compressive Strength of Pozzolanic Concrete"* was Published in IUBAT Reviews, 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, (Raju et al., 2024).

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III. RESEARCH DESIGN

In this work, Sodium Hydroxide liquor was used for the treatment of the Jute fiber (NaOH). The process is a "Sulphonation Method". 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 department faculty of Engineering, Mewar University. The sodium hydroxide used is illustrated in figure 1, then the Treated Jute fiber is shown in the below figure 2.

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.

Fig 1 NaOH - Used for Modification of Jute

Fig 2 Modified Jute Fiber

The treated Jute Fiber of 20mm uniform Lengths was added in the mix both in percentages 1, 1.5 and 2%. The Cylinder is (150 dia. X 300 h) mm in length. This experiment tested 36 Beams 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.

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. The Volume of Beams is (0.15 x 0.15 x 0.7) = 0.01575m^3 x 1.54 and The volume of Wet Beam = 0.024255m^3. The Mix Proportion and Material Quantities for the 36 Beams are presented in Table 1, below:

Table 1 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**

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➢ *Experimental Investigation:*

Firstly, the 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 below:

Fig 5 Mixing with Jute

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 6, likewise figure 7 shows 0% slump.

Fig 6 1% Slump

Fig 7 0% Slump

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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 cylinders:

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 beam specimens used for testing are illustrated in figure 8 inside water tank also below.

Fig 8 Curing in a Water Tank

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) is used for this test. The UTM typically has accessories or attachments for performing flexural tests. Therefore, figure 9 shows the flexural test setup and figure 10 illustrated failed beam sample immediately after failure in the UTM.

Fig 9 Setting Distance b/w Support

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Fig 10 Failed Beam

The water absorption test is important because it affects the material's strength, durability, and overall performance in concrete and other applications. The test is determined by immersing the material in water for a specified period, and then measure the increase in weight due to water absorption. The weighing process during the water absorption test is illustrated in figure 11, then figure 12 shows an oven for sample drying.

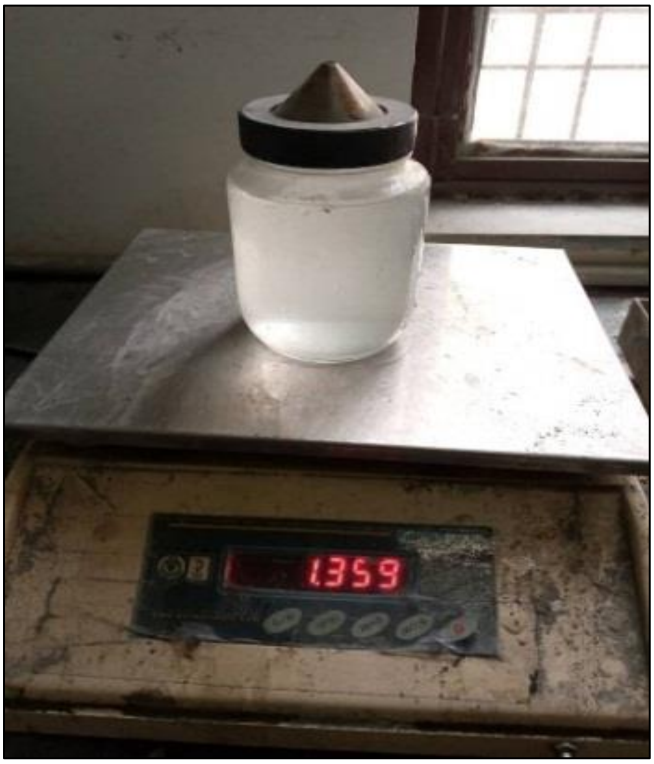

Fig 11 Weighing Filled Pycno.

Fig 12 An Oven

The Sieve Analysis process helps to determine the particle size distribution of the sample, which is essential for various applications in construction and materials science. Figure 13 illustrated the sieve analysis procedure and the sieve stack for sieve analysis is demonstrated in figure 14 below:

Fig 13 Weighing

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Fig 14 Sieve Stack

The Data Analysis Methods is a Statistical Method, therefore, some software tools and machine learning were used in this 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.

➢ *Machine Learning Background:*

The Random Forest algorithm workflow and the Multiple Linear Regression algorithm workflow were best introduced in figure(s) 15 and 16 below in order to make it easier to understand the workflow of each model:

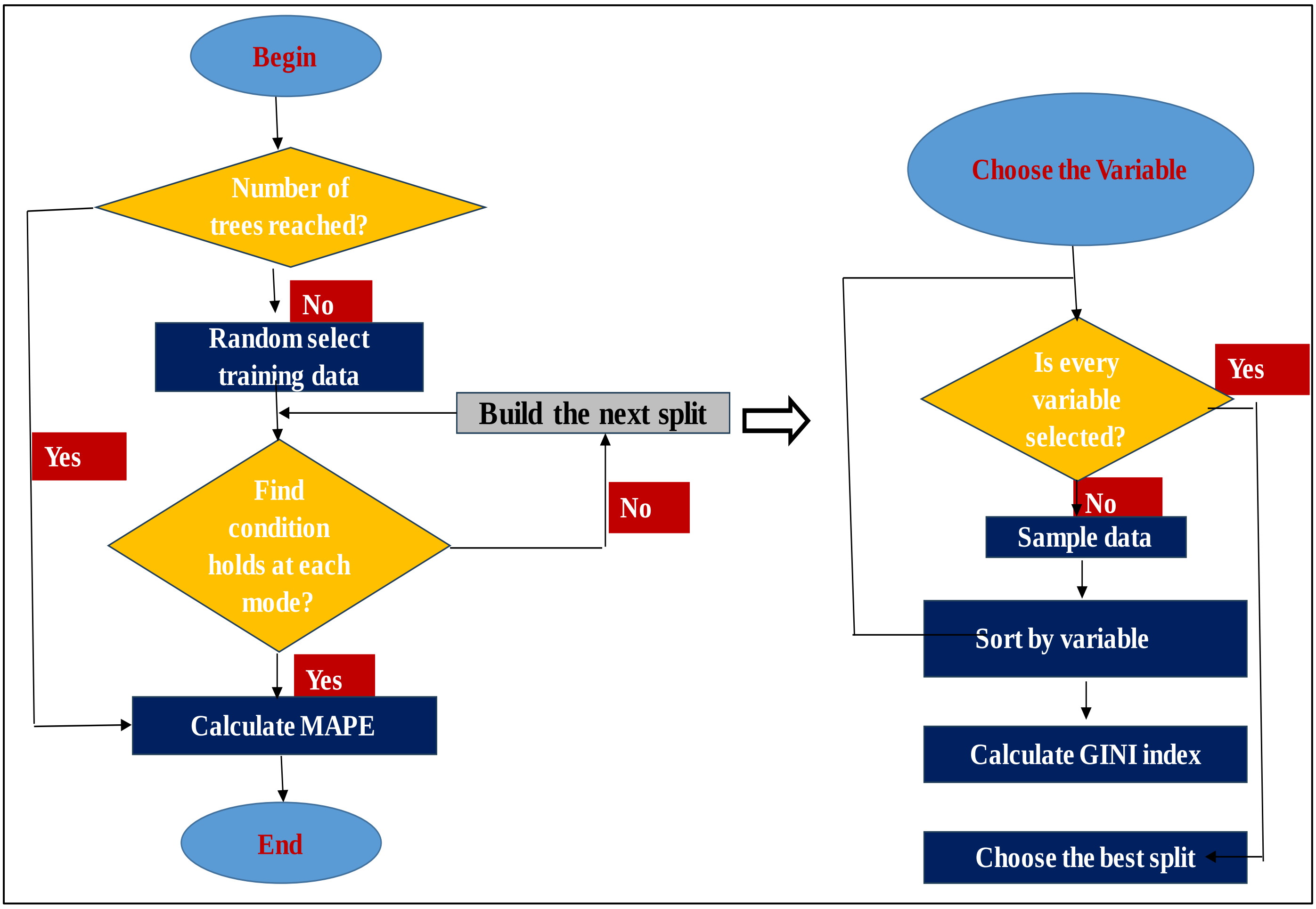

Fig 15 Flowchart for Random Forest Algorithm Procedure

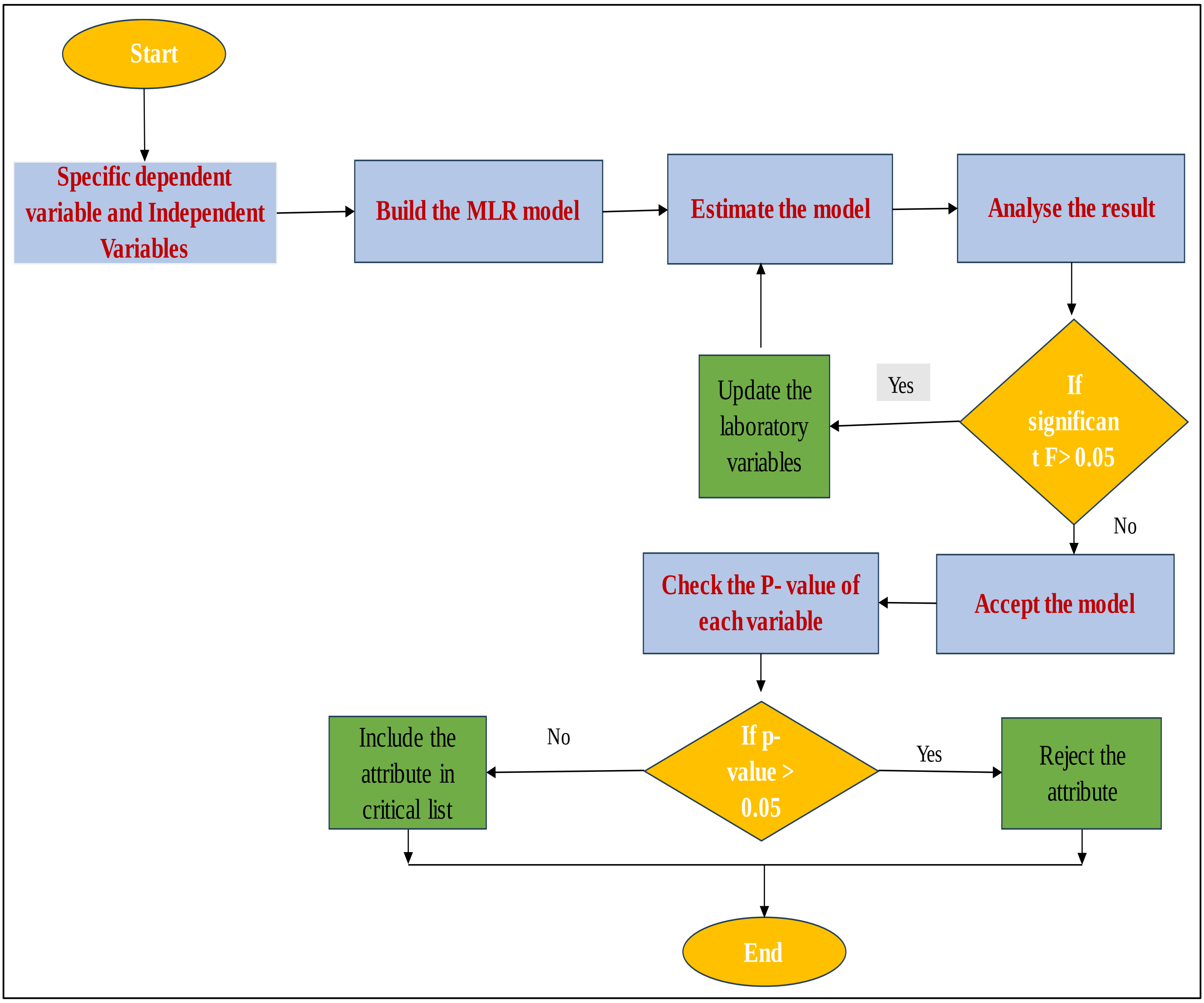

Fig 16 Flowchart for Multiple Linear Regression Algorithm Procedure

IV. EXPERIMENTAL RESULTS

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.

- Material Properties: The results of specific gravity and water absorption for coarse aggregate are presented in table 2, then the properties of fine aggregate are summarized in table 3, And also, the test results for treated jute fiber illustrated in the below table 4:

Table 2 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		

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Table 3 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 4 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**		

- Particle Size Distribution: The Sieve Analysis results for Fine Aggregate are displayed in table 5 below:

Table 5 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**		

- Properties of Fresh Concrete: The Slump values and workability results are presented in the below figure 6:

Table 6 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

- Mechanical (Hardened) Properties of Concrete: The overall strength test results for different curing days are given in table 7 below:

Table 7 Overall Strength Test Results with Varying Fiber Contents and Curing Days

Sample ID	Fiber (%)	Curing Age	Flexural (MPa)
TJF0	**0%**	7	4.4
TJF0		14	5.3
TJF0		28	6.5

TJF1	**1%**	7	5.3
TJF1		14	6.5
TJF1		28	7.8
TJF1.5	**1.5%**	7	5.5
TJF1.5		14	6.6
TJF1.5		28	7.5
TJF2	**2%**	7	5.2
TJF2		14	6.4
TJF2		28	7.3

V. DATA ANALYSIS AND INTERPRETATION

The analysis of the data presented above, was plotted below, including Bar charts, pie chart, and Histogram, using the Average Mean Scores (MPa) of each of the experimental results.

➢ *Descriptive Statistics including the Measures of Central tendency i.e., 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 was used in plotting the graphs. The results of slump workability tests are plotted in figure 17, figure 18 shows the sieve analysis results, figure 19, 20 and 21, presented the flexural strength results at 7,14 and 28 days. Moreover, Figure 22 shows the Comparison between Flexural Strengths at 7, 14 and 28 days.

- Graphical Representation of Results (Histograms, Bar charts & Line Graphs):

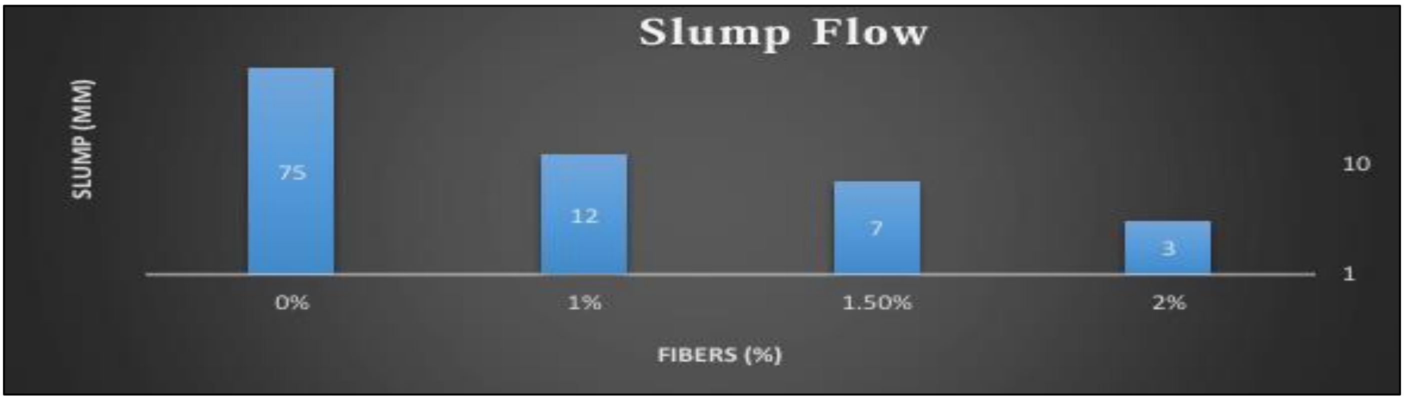

Fig 17 Slump (Workability) Test Results

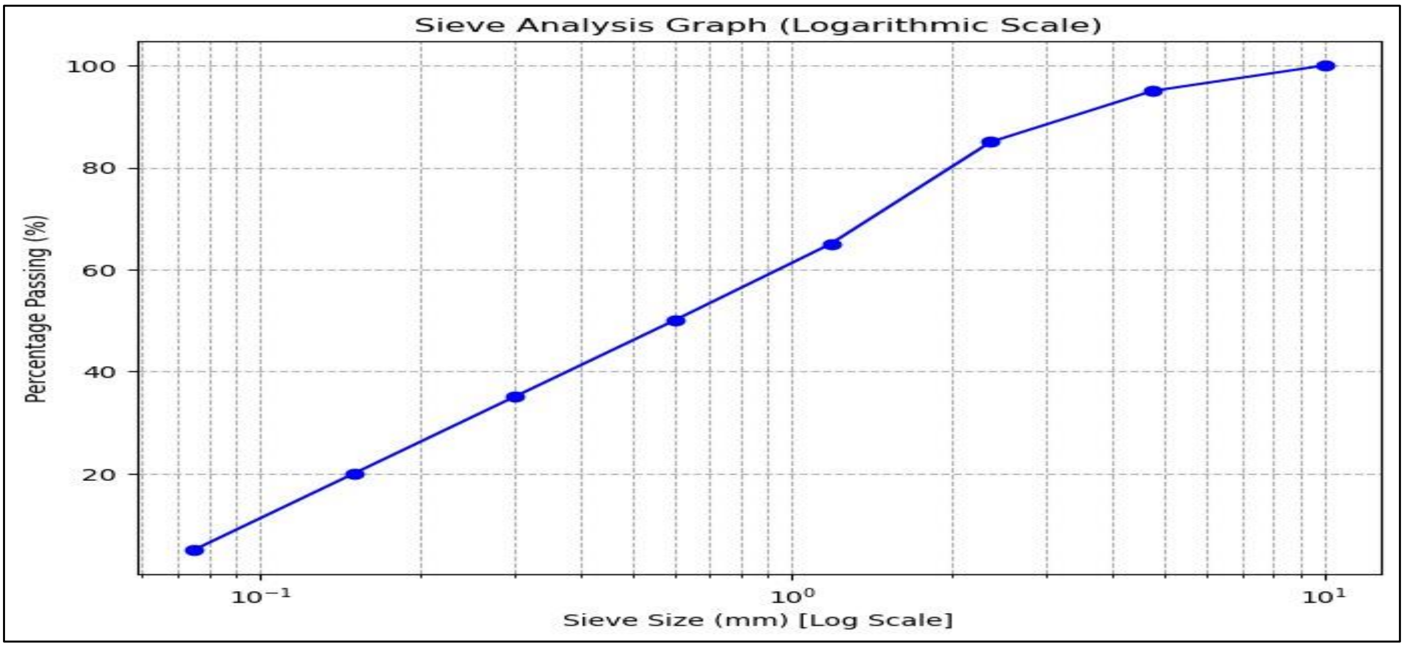

Fig 18 Sieve Analysis Results Graph

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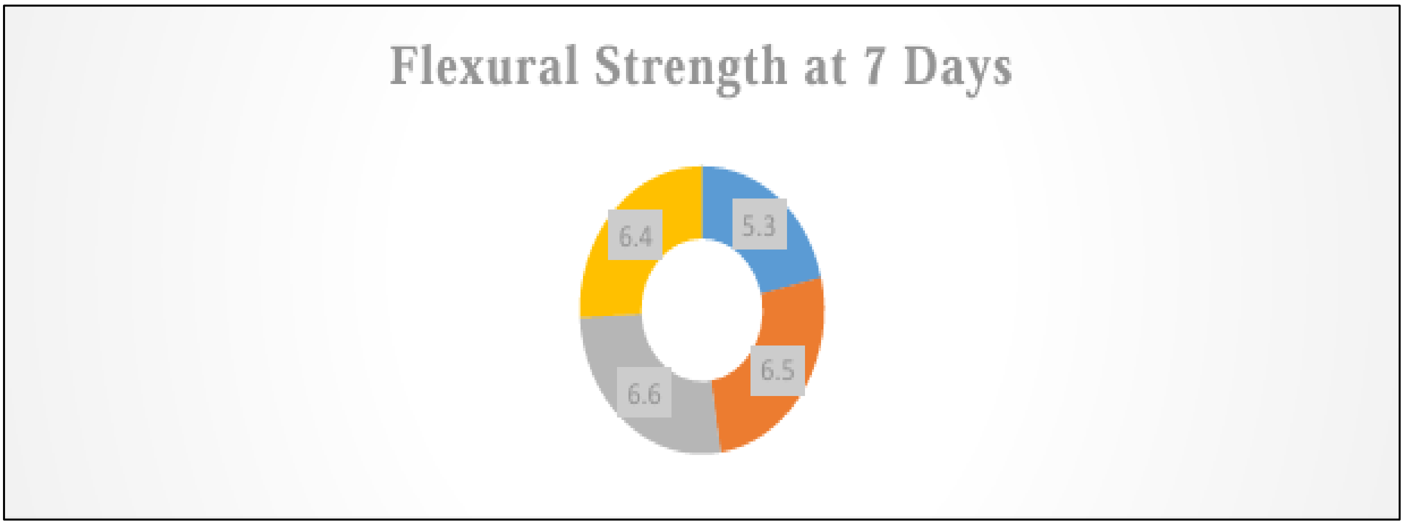

Fig 19 Flexural Strength - 7 Days Results

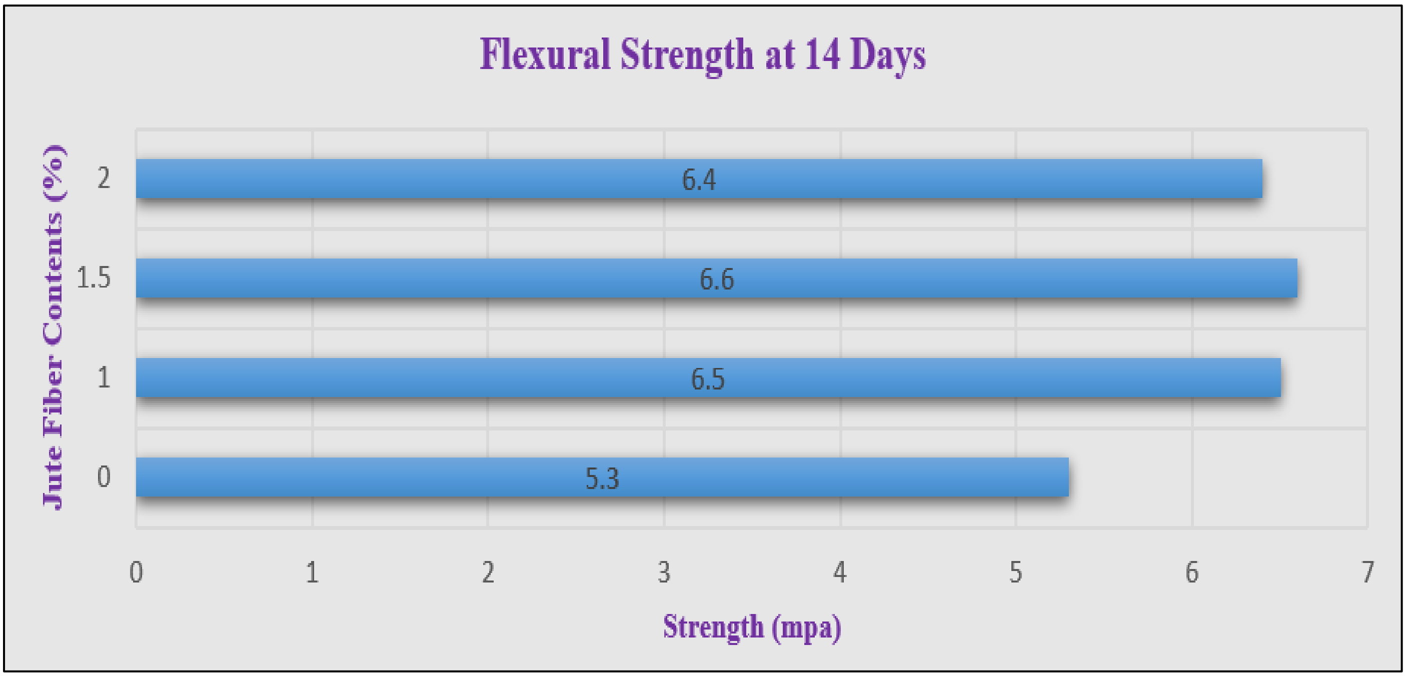

Fig 20 Flexural Strength - 14 Days Results

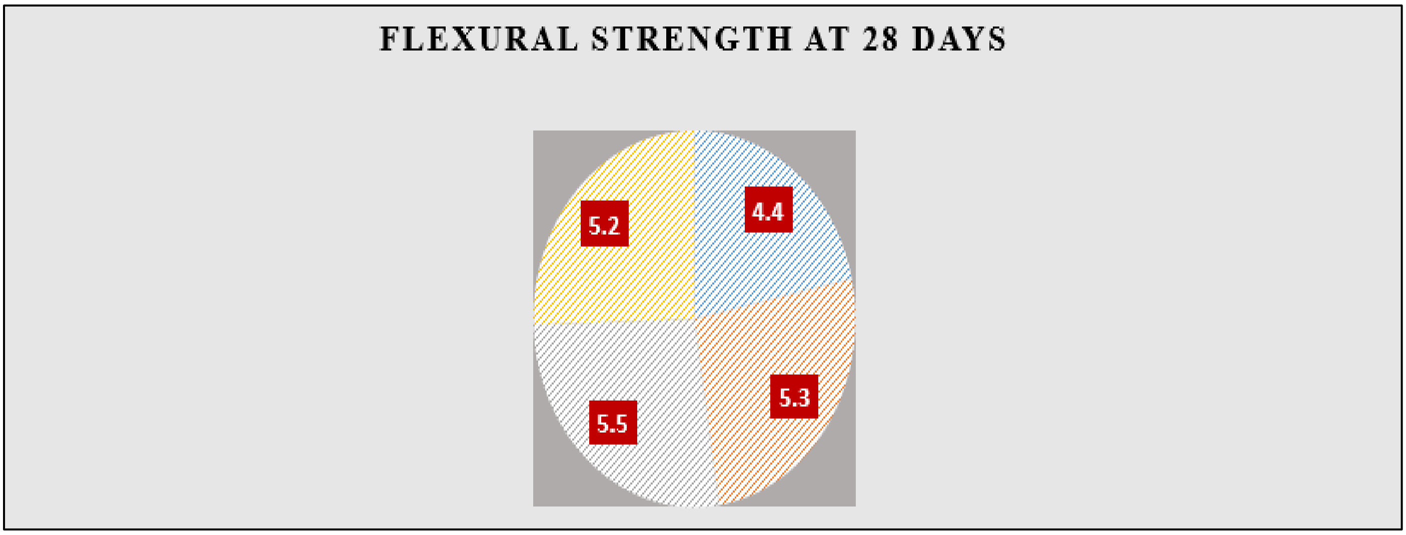

Fig 21 Flexural Strength Results at 28 Days

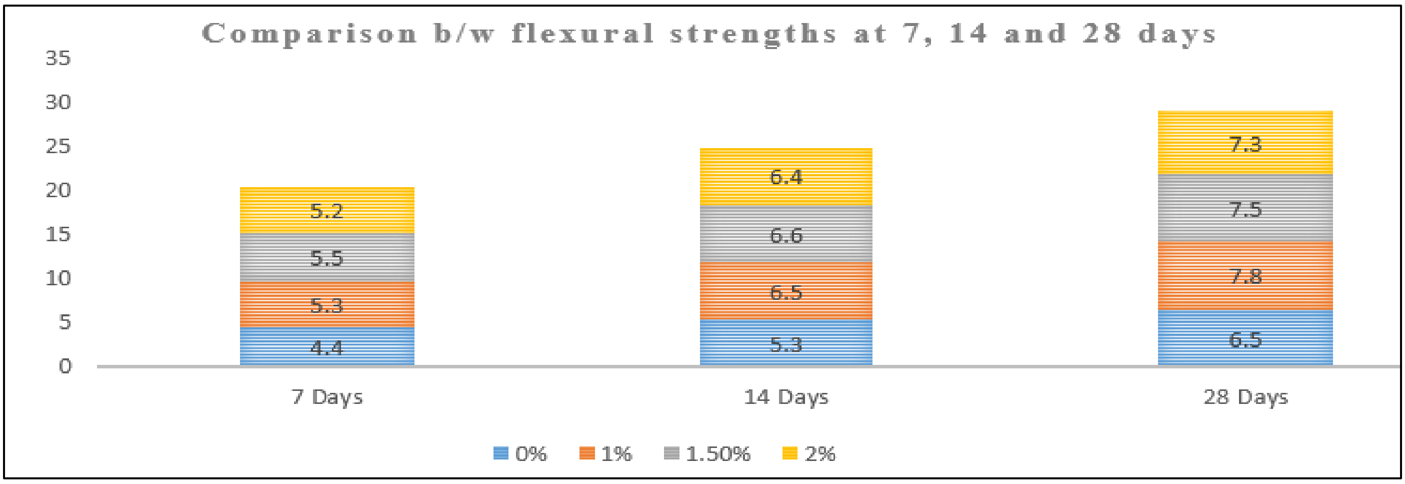

Fig 22 Comparison between Flexural Strengths at 7, 14 and 28 days

- Inferential Statistics: The Parametric correlation test conducted in the study was "Analysis of Variance". (ANOVA) Results is used to check the significant differences between groups, If the *p-value* is less than the *0.05* significance level, reject the null hypothesis, indicating a significant effect of fiber content on the strength properties. But If the *p-value* is greater than the significance level, do not reject the null hypothesis. The hypothesis statement used for the research is, "The incorporation of modified jute fibers doesn't significantly diminish the Flexural Strength". Therefore, The ANOVA results for flexural strengths are summarized in *Table 11 below:*

Table 8 Compressive, Flexural Strengths ANOVA Table

ANOVA Table for Flexural Strength				
C (Fiber Content)	2.550000	3.0	0.691995	0.582174
Residual	9.826667	8.0	NaN	NaN

VI. REALIZATION OF ML RESULTS

The Machine Learning Models and Simulation were the "Multiple Linear regression and Random Forest" 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.

- *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 9 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

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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

VII. VISUALIZATION OF ML RESULTS

In this section, Figure 23 and 24 displayed the Correlation Matrix of Flexural Strength with varying Modified Jute Using Multiple Regression Model, then Figure 25, shows The Actual vs predicted Random Forest Results for F.S.

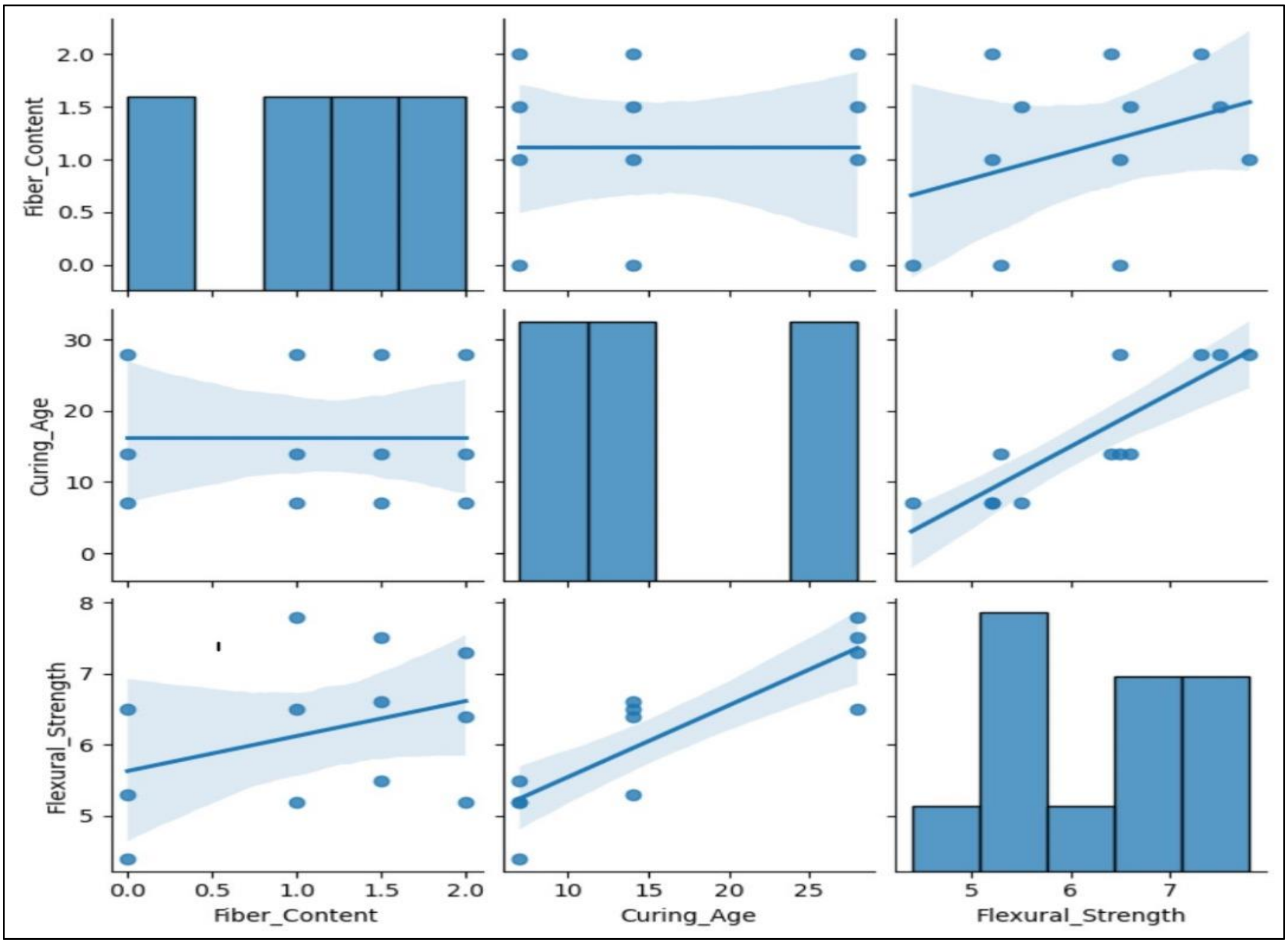

Fig 23 Correlation Matrix of Flexural Strength with Varying Modified Jute Using Multiple Regression Model

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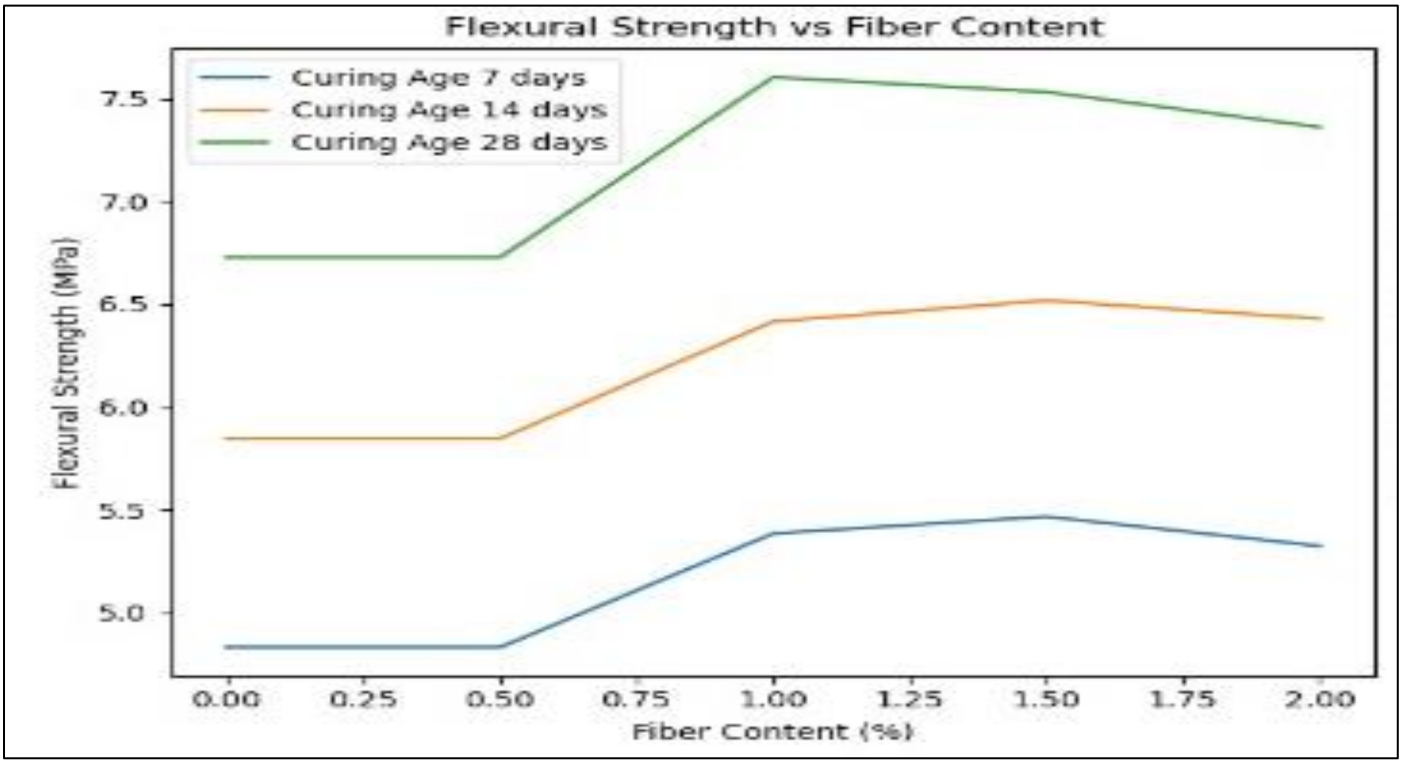

Fig 24 Correlation Matrix of F.S with Varying Modified Jute Using a Multiple Regression Model.

This simulation is also used to predict Flexural 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 39.

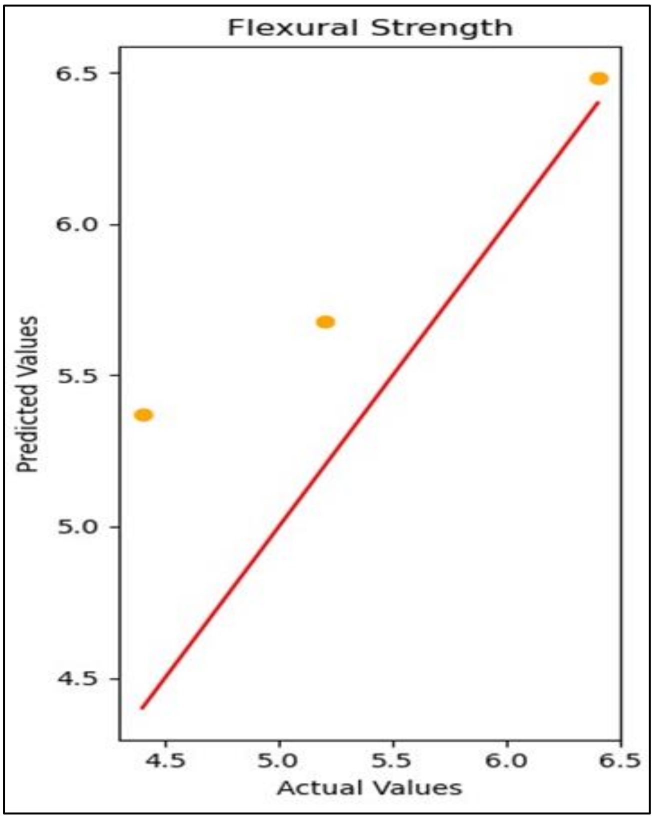

Fig 25 The Actual vs Predicted Random Forest Results for F.S

VIII. DISCUSSION OF 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 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 Machine Learning (ML) and Simulation: 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

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- Content X Curing - Age) to account for the combined effect of these variables.

The *Multiple Regression Analysis* for *Flexural Strength* is also done with 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.

Secondly, Random Forest Regression Model - Machine Learning is 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 flexural strength. 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. 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.

The Random Forex model performs best for predicting flexural strength, where the predictions closely align with actual values.

Then for the 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.

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.

The Ho1, Ho2, and Ho3 are all supported by the results, as the p-values for flexural 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.

IX. SUMMARY

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 for the flexural 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 strength, particularly at 1% fiber content.

The hypothesis testing in this study aimed to determine whether the incorporation of modified jute fibers significantly affects the mechanical properties of concrete, including flexural strengths. The hypotheses tested was the "*Ho: The inclusion of modified jute fibers does not significantly enhance the flexural strength of concrete".*

Using ANOVA (Analysis of Variance), the p-values for flexural 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 the flexural 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 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 flexural strengths with high accuracy, though predictions.

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

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X. CONCLUSION

The experimental results highlight the impact of modified jute fibers on concrete performance, particularly in terms of 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 strength.

The machine learning models used in the study provided reliable predictions of flexural strengths. Multiple linear regression and Random Forest regression effectively modeled the influence of curing age and fiber content on the mechanical properties of concrete.

The hypothesis testing performed using ANOVA revealed that modified jute fibers do not significantly decrease flexural 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 the flexural strength, particularly at 1% fiber content.

RECOMMENDATION

➢ *Based on the Findings of this Study, Several Recommendations can be Made for Future Research and Practical Applications:*

- The use of 1% modified jute fiber is recommended for improving the flexural strengths of concrete.
- 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.
- Further and more Machine Learning models should be applied in predicting the mechanical properties of fiber-reinforced concrete, and explore other algorithms to improve prediction accuracy.
- 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.
- 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.

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