DESIGN AND COST ANALYSIS OF FLEXIBLE PAVEMENT: SUBGRADE REINFORCED WITH JUTE AND POLYPROPYLENE FIBRE

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Abstract - *This research focuses on the improvement in the construction of flexible pavement, which is vital for strong transportation networks and economic growth. In this research, the focus is on improving the strength of the subgrade soil(measured using the California Bearing Ratio Test) by introducing ground improvement materials like Jute Fibre and Polypropylene Fibre. The addition of these reinforcements leads to an increase in the CBR value of the subgrade which leads to a decrease in the thickness of the overall pavement design. This helps in the improvement of pavement performance while lowering construction costs and placing a strong emphasis on creative and sustainable road-strengthening techniques. So we can say that this research not only enhances pavement engineering but also encourages the creation of ecologically friendly infrastructure using economical methods.*

Key Words: California Bearing Ratio Method, Flexible Pavement, Pavement Thickness, Subgrade, IRC 37, Subgrade CBR, Jute Fibre, Polypropylene Fibre, Cost Analysis, Sustainability

1. INTRODUCTION

A sustainable transport network is one of the most important necessities in this age, and the quality of the subgrade of pavement plays a pivotal role in a road's lifespan and usefulness.

Black-top pavements that exhibit rutting, pushing, waves, and corrugations are usually the result of inadequate subgrade conditions (Khanna & Justo, 2011). The majority of transportation-related research has concentrated on improving and fortifying the soil used as the subgrade for flexible pavements (Pandit et al., n.d.). The findings of laboratory and field experiments that evaluate the impact of different reinforcing techniques on pavement performance are presented by (Rajagopal et al., 2014). The results of their experiment demonstrate that adding reinforcement enhances the strength, stiffness, and endurance of pavement systems under repeated loads.

The process of stabilizing soil is to enhance its engineering performance and make it useful for a range of engineering projects (Prasanna & Nm, 2020). The performance, longevity, and efficacy of a pavement are determined by the stability of the subgrade soil, which is the foundation of any pavement (Hamid & Shafiq, n.d.). Jute fibres and geotextiles have both been effectively utilised to reinforce soils to increase their bearing capacity (Hossain, 2015). One of the most significant utilities is geo-reinforcement, which is primarily used to mechanically increase the strength of soil that has been specially designed for the building of geo-structures (Kumar et al., 2022). According to the results of laboratory testing, this woven geotextile can be used to build medium-traffic unpaved roads both as a separation layer and as a reinforcing material (Basu et al., 2009). When building medium-traffic roads, jute geotextile can be used as both an anchoring material and a separation layer (Pavani et al., n.d.). Jute fibre reinforcement has considerably improved the strength and stiffness properties of soil, according to CBR and Triaxial tests (Lal et al., n.d.). Enhancing the soil leads to an increase in its strength, ductility, bearing capacity, and ability to resist deformations ("Improvement in Subgrade Characteristics of Soil Reinforced With Jute Fibre," n.d.). A single layer of horizontal reinforcement placed within the soil significantly raises the CBR value of the soil (Choudhary et al., 2012). When two layers of jute fibre are combined, the soaked CBR value and maximum dry density both rise (R & Muralidhar, 2015). As fibre length and diameter increase, so does the soil's CBR value (Singh & Bagra, 2013).

The strength and ductility of soils may be significantly increased by combining sand, lime, and polypropylene fibres (Meddah et al., 2022). When soil dry density rises, the fibre/soil interfacial peak strength (IPS) and interfacial residual strength (IRS) decrease, whereas soil water content rises (Tang et al., 2010). When LDPE is added, the softening point tends to rise, indicating improved resistance to deformation (Al-Hadidy & Tan, 2009).

This study investigates the use of polypropylene and jute fibre for improving the ground during pavement building. Important qualities were examined in soil samples taken from university property. There was a percentage improvement with appropriate fibre content when the California Bearing Ratio (CBR) values of the reinforced and unreinforced samples were monitored. The biodegradability and accessibility of jute, along with the adaptability of polypropylene, make them ideal materials for improving pavement performance.

Overall, the study highlights how the use of jute and polypropylene fibre in load distribution systems may enhance the structural integrity and longevity of pavements.

2.MATERIALS AND METHODS

2.1 Materials Used

2.1.1 Soil Samples

The soil sample used for this project was taken from the premises of our campus(i.e. the construction site near the sports complex).

2.1.2. Jute Fibre

Jute is highly valued for its exceptional tensile strength and biodegradability, making it a perfect material for strengthening subgrade soil. The aspect ratio of the jute fibre used was 150.

2.1.3. Polypropylene Fibre

Given its inherent resilience, polypropylene fire is a good choice for providing stability in various weather circumstances for reinforcing flexible pavements. Notably, polypropylene fibre's resilience to chemicals and moisture increases pavement construction's dependability even further. The aspect ratio of polypropylene fibre used was 150.

2.2 TESTS PERFORMED

To find out the type of soil sample we were working with, certain laboratory tests were performed as given in Table 1.

Table 1: Grain Size Analysis of soil

Properties	Values
Fineness Modulus	3.10
Uniformity Coefficient, C_u	4.12
Coefficient of Curvature, C_c	0.70
Type of Soil	Coarse-Grained Soil

Table 2: Index properties of soil sample

Index Properties	*Values*
Specific Gravity	*2.30 Kg/m³*
Plastic Limit(%)	*Impossible to determine*
Liquid Limit(%)	*18.00*
Plasticity Index	*Non-Plastic*

Sieve Analysis, Specific Gravity(Density Bottle method), Liquid Limit(Casagrande Method), and Plastic Limit Tests were performed as per IS:2720 1985 and values were identified and grouped as per IS 1498-1970.

According to the values obtained, we concluded the soil was Poorly Graded Sand.

2.2.1. Modified Proctor Test

To achieve the optimum moisture content, unreinforced samples and samples reinforced with 0.5%, 1%, 2%, and 3% of jute fibre and polypropylene fibre underwent heavy compaction test.

Figure 1 shows the difference in the OMC and MDD values by adding different percentages of jute or polypropylene fibres. The OMC of the sample ascends as the percentage of fibre increases for both samples reinforced with jute or polypropylene fibres, whereas there is a decrease in MDD after a certain percentage of fibre is added.

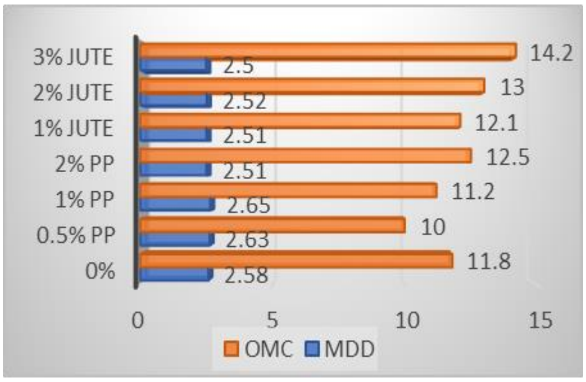

Figure 1: MDD and OMC values of samples at different fibre contents

2.2.2 California Bearing Ratio(CBR) Test

The CBR test is used toconstruct pavements to check the strength of the soil. The test was performed for soaked and unsoaked samples with the addition of OMC (Optimum Moisture Content) obtained from theModified Proctor Test. For the soaked soil condition, the mould was submerged under waterfor 96 hours (equivalent to 4 days). The CBR values at 2.5mm and 5mm penetration are calculated using the formula,

$$CBR_{2.5mm} = \frac{P_t}{1370} X\ 100 \quad (1)$$

$$and, CBR_{5mm} = \frac{P_t}{2055} X100 \quad (2)$$

The higher of the two values acquired is taken as the CBR value of the subgrade, which usually occurs at 2.5 mm penetration, but if the value at 5mm penetration is higher, then it is taken as the CBR value after performing the tests multiple times to ascertain it.

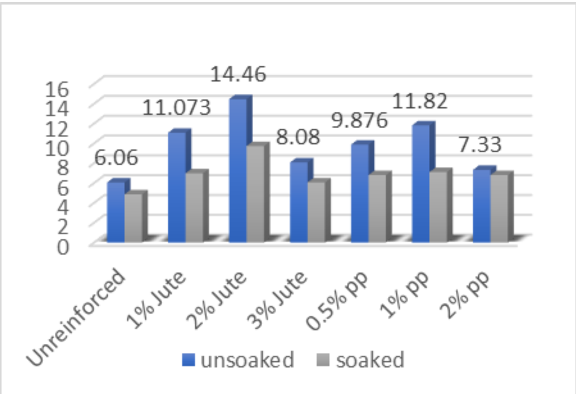

Figure 2: CBR values of soil at different fibre contents

Figure 2 represents the comparison of the CBR values when fibres of different percentages were added to the subgrade soil. From the figure, we can assume the Optimum Fibre Content will lie around 2% in the case of Jute Fibre and 1% for Polypropylene Fibre.

We plot the following graphs to get the optimum fibre content at which the CBR value is the highest.

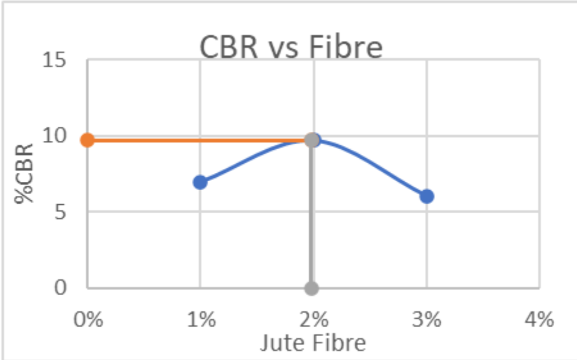

Figure 3: Graph between CBR value and %Jute Fibre

The Optimum Fibre Content for Jute Fibre (as per Figure 3) is 1.89%.

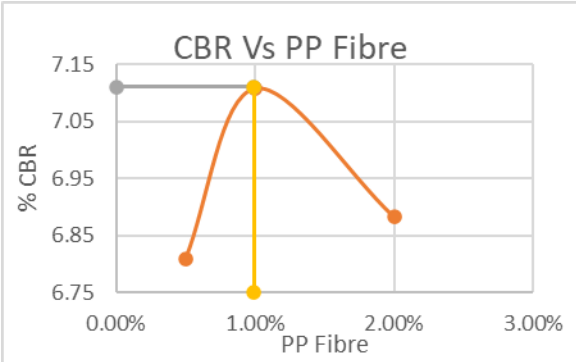

Figure 4: Graph between CBR value and %Polypropylene Fibre

The Optimum Fibre Content for Polypropylene Fibre (as per Figure 4) is 0.99%.

3. DESIGN OF FLEXIBLE PAVEMENT USING IRC GUIDELINES

To design the thickness of the flexible pavement, we assumed a Two-lane single-carriageway road,

Initial traffic, A = 1200 CVPD, and Lane distribution factor, D = 0.5 (as per IRC 37 Guidelines).Annual growth rate of commercial vehicles given in decimal, r = 0.05, Lane distribution factor, D = 0.5

Vehicle Damage Factor, F = 3.5 VDF (as per IRC 37 Guidelines)

Assuming Design Life, n = 15 years

and, Cumulative number of standard axles to be catered for in the design in terms of Million Standard Axle (MSA) = N, where,

$$N = \frac{365 \; x \; [(1+r)^n - 1]}{r} \; x \; A \; x \; D \; x \; F \tag{3}$$

$$N = \frac{365 \; x \; [(1+0.05)^{15} - 1]}{0.05} \; x \; 1200 \; x \; 0.5 \; x \; 3.5$$

Therefore, N = 16.54 MSA

Using the value of N we obtained and the subgrade CBR, we can now find the thickness of flexible pavement as per IRC 37 guidelines.

Figure 5 shows the pavement thickness of the soils which were reinforced with Jute Fibre and Polypropylene Fibre (at their Optimum Fibre Contents) that were obtained while following the guidelines of IRC37 2012. As we can see from the graph, the thickness of reinforced subgrades is lower than that of the unreinforced subgrade.

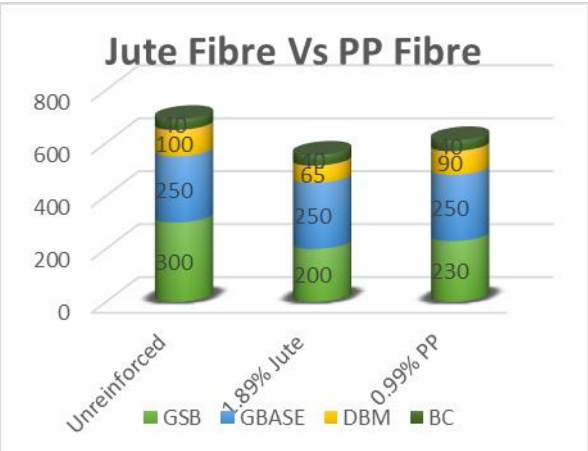

Figure 5: Pavement thickness comparison of the re-inforced subgrade with Optimum Fibre Content

4. COST ANALYSIS

The cost analysis for initial construction for each layer is done as per the average cost of the construction pavement layer researched.

Table 3: Rate of flexible Pavement Layer per cubic meter

Layer	Cost/m³ (Rs)
BC	8,511
BM	7,516
WMC	1,450
Granular Subbase	1,785

Prime Coat = Rs 215,000/Km
Tack Coat = Rs 210,000/Km

From the following rates, we calculate the cost analysis for the different kinds of flexible pavement with different subgrade values.

Firstly, we have the cost analysis of Unreinforced Flexible Pavement as given in Table 4

Table 4: Cost/km of Unreinforced pavement

	Length (m)	Width (m)	Thickness (m)	Cost/km (Rs)
BC	1000	10	0.04	3,404.400
BM	1000	10	0.1	7,516,000
WMC	1000	10	0.25	3,625,000
Granular Subbase	1000	10	0.3	5,355,000

This gives a total of Rs 20,325,400, including the prime coat and tack coat.

The cost analysis of flexible pavement with the subgrade reinforced with jute fibre is given in (table5)

Table 5: Cost/km of pavement with Subgrade reinforced with Jute Fibre

	Length (m)	Width (m)	Thickness (m)	Cost/km (Rs)
BC	1000	10	0.04	3,404.400
BM	1000	10	0.065	4,885,400
WMC	1000	10	0.25	3,625,000
Granular Subbase	1000	10	0.2	3,570,000

This gives a total of Rs 15,909,800, including the prime coat and tack coat.

Similarly, the cost analysis of the subgrade reinforced with polypropylene fibre is given in Table 6.

Table 6: Cost/km of pavement with Subgrade reinforced with Polypropylene Fibre

	Length (m)	Width (m)	Thickness (m)	Cost/km (Rs)
BC	1000	10	0.04	3,404.400
BM	1000	10	0.09	6,764,400
WMC	1000	10	0.25	3,625,000
Granular Subbase	1000	10	0.23	4,105,500

This gives a total of Rs 18,324,300 (including the prime coat and tack coat).

Figure 6: Comparison of cost analysis between three different pavement compositions

Figure 6 represents the comparison of the cost analysis of the three pavements with different subgrade CBR values i.e. Flexible pavement design without unreinforced subgrade, Flexible pavement design with subgrade reinforced using Jute Fibre, and Flexible pavement design with subgrade reinforced using Polypropylene Fibre.

The percentage reduction in the cost of design in the case of subgrade reinforced with Jute fibre as compared to unreinforced subgrade is 21.725%, whereas the reduction in the case of subgrade reinforced with Polypropylene Fibre is 9.845%.

5. CONCLUSION

Based on the studies done, we can see that the California Bearing Ratio (CBR) values significantly increased when polypropylene and jute fibres were used for subgrade reinforcement. This suggests promising advancements in flexible pavement design. Jute fibre, which is naturally occurring and biodegradable, integrates well with sustainability goals while promoting accessibility and environmental benefits. On the other hand, polypropylene fibre, while not biodegradable, provides toughness.

The highest CBR value obtained for Jute Fibre was 9.87%, whereas that of Polypropylene fibre was 7.11%.

We can also see the percentage reduction of the initial cost of construction reduced for the reinforced subgrade i.e. 21.725% for the Jute Fire reinforced subgrade and 9.845% for the Polypropylene Fibre reinforced subgrade.

Although the CBR value of Jute Fibre is higher as compared to that of Polypropylene Fibre, Jute Fibre may decompose over time which can cause an issue to the construction. Hence, by carefully considering engineering requirements and the environmental impact needed in the area, jute or polypropylene fibres may be used for the optimization of flexible pavement designs.

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