Studies on serviceability of jute geotextiles in unpaved roads at different rainfall conditions

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Geotextiles in roads provide better reinforcement and drainage functions. In this paper, 760 g/m² grade jute geotextiles/geojute were laid in unpaved road designs with and without sand layer, for durations of 30, 60 and 90 days, and were subjected to 50 and 100 mm/hour simulated rainfall. It was observed that the tensile strength, breaking elongation and puncture resistance properties, which influence the reinforcement function of jute geotextiles are significantly influenced by the presence of sand layer in road design, which was followed by rainfall intensity and duration of usage. The average pore size which influences the drainage function of jute geotextiles was highly influenced by the sand layer and rainfall intensity.
Key words*: jute geotextiles, reinforcement, drainage, unpaved roads, rainfall intensity*

1. Introduction

Roads are the important mode of transportation, which are responsible for the infrastructure development and economic growth of a country. Many types of roads exist around the world; among these paved and unpaved roads are most common. Paved roads are the permanent roads with aggregates and reinforcing materials, whereas the unpaved roads are the temporary roads with simple subgrade soil and aggregates. Use of geotextiles in the paved and unpaved roads increases their life and minimizes periodic repairing costs. Geotextiles offer better reinforcement and drainage in subgrade structure, which avoids the reflective cracking of roads [1-2]. In recent years, lots of research and on-site trials have been done on ageing of paved and unpaved roads reinforced with geotextiles. Many of these studies report an increase in the CBR value (California Bearing Ratio- ratio between the penetration strength of road subgrades on construction sites to the base courses of same soil) of roads after the incorporation of geotextiles [3-6].

Reinforcement (under-laying) of geotextiles in unpaved roads is commonly known as soil-fabric-aggregate (SFA) system, which reduces aggregate consumption up to 33% because of better performance in membrane support or membrane reinforcement, shear reinforcement against shear stress, and the lateral confinement. Moreover, geotextiles keep the aggregates separated from the subgrade soil, and drain out the water from the road structure [7-9].

Geotextiles used in road laying are generally made of natural or synthetic fibres or combination of both. Geotextiles made of synthetic fibres like polypropylene, polyethylene, etc are durable with high strength and reinforcement, whereas the geotextiles made of natural fibres like jute, coir, etc are less durable but offer biodegradability and better moisture content. Hence, synthetic geotextiles are used in permanent or paved roads, and biodegradable natural geotextiles are used in temporary roads (construction site and mining roads) or unpaved road construction. Biodegrability of natural geotextiles also makes them a preferred choice due to environmental reasons [10-13]. Past studies reported that the use of jute geotextiles in soft subgrade unpaved roads provides better performance and reduces the rate of plastic deformation (rut or crack development) [14-17]. Although it is expected that before the natural fibre geotextiles degrade, the unpaved roads have achieved the required consolidation and reinforcement. Few researchers claimed to improve the durability of jute fibres or geotextiles by modifying the fibres [18-19]. But none of the study has been carried out on the durability and performance of these jute geotextiles after usage in the soil. The time dependent serviceability of these natural geotextiles are expected to be influenced by the soil type, road design, rainfall intensity (defined as the ratio of the total amount of rainfall depth during a given period to the duration of the period, expressed in depth units per unit time, normally mm/h) and trafficking procedure. The moisture transmission and CBR value were observed to be improved by using sand layer along with jute geotextiles, in subgrade structure of road design [9, 20-21].

In this paper, the time dependent serviceability of 760 g/m^2 grade jute geotextileswere studied at varied rainfall intensity (50 and 100 mm/hr) and road designs (with and without sand layer) using lower Himalayan soil. Among different properties of geotextiles, tensile strength influences the shear behavior of the soil (reinforcement function), puncture resistance influences the soil to aggregate separation function, whereas the poresize of geotextile influences the drainage function of road subgrades. These three functions are most important for the better performance and serviceability of geotextiles. Therefore to evaluate the serviceability of jute geotextiles, tensile strength, puncture resistance and pore size of jute geotextiles have been studied before (control samples) and after using them in unpaved road designs for different durations of 1, 2 and 3 months.

2. Materials and methods

2.1. Materials

760 g/m^2 grade woven jute geotextiles (Tosa jute) was used in this study [22]. Tab.1 shows the characteristics of jute geotextiles analyzed as per the standard procedures and ASTM D 4751-12 [23-24].

Tab.1 Characteristics of jute geotextiles (760 g/m^2- grade)

S. No	Specifications	Values (warp × weft)
1	Actual mass per unit area (g/m^2)	745
2	Weave	2/1 weft rib
3	Ends/cm × Picks/cm	10 × 5
4	Yarn linear density (tex)	385 × 640
5	Tensile strength (kN/m)	25 × 25
6	Elongation at break (%)	10 × 10
7	Thickness (mm)	2
8	Apparent opening size (microns)	110.29

2.2. Methods

Lower Himalayan soil which is sandy loam in nature with 40% of sand, 40% of silt and 20% of clay, having a pH of 6-8, was used in the study. Two type of unpaved road designs; with and without sand layer were prepared in laboratory, using sheet metal boxes of dimensions 600 mm length, 450 mm width and 350 mm height (Fig.1). In road design without sand layer, jute geotextiles (600 mm length x 450 mm width) were laid over 200mm of soil and covered with100 mm of stone aggregates (Fig.1a). Inroad design with sand layer, sand layer of 20 mm is laid between the soil and stone aggregate, while the required jute geotextiles was laid at the middle of sand layer (10 mm of sand at the top and bottom of jute geotextiles, as show in the Fig.1b [16].

The road designs were supplied with surface soft water with the garden sprinkler, equivalent to 50 and 100 mm/hr rainfall intensity, according to the average rainfall received in the lower Himalayan region [25]. Hence, 1125 and 2250 ml of water was supplied (depending upon the area of the test trays) to the test trays having different road designs. A small hole of 1 cm diameter was provided at the bottom four corners of the tray for draining to simulate the practical soil seepage behaviour. Fig.2 shows the experimental designs.

2.3. Test methodology

Jute geotextiles were removed from all the road design models after an interval of 30, 60 and 90 days of usage. The samples were then allowed to dry in standard atmospheric conditions for 3 days (27 ± 2 °C; 65 % RH) as shown in Fig.3. The drying of soil allowed easy removal of the soil particles from the geotextile surface. The dried samples along with the control samples were tested for tensile strength, puncture resistance and pore size, to evaluate the reinforcement and drainage performance of geotextiles.

Tensile strength and breaking elongation of geotextiles were evaluated both in warp and weft direction at a gauge length of 100 mm, according to ASTM D4595- 11 standards using universal tensile strength tester. Sample size of 300 mm length and 200 mm width were used [26-29]. To evaluate the time dependent serviceability of jute geotextiles, tensile strength's retention % at different service duration was calculated using equation (1). Similarly the retention% of breaking elongation was also calculated.

$$Retention\ \% = \frac{Tensile\ strength\ of\ sample\ at\ different\ service\ duration}{Tensile\ strength\ of\ control\ sample} \times 100 \qquad (1)$$

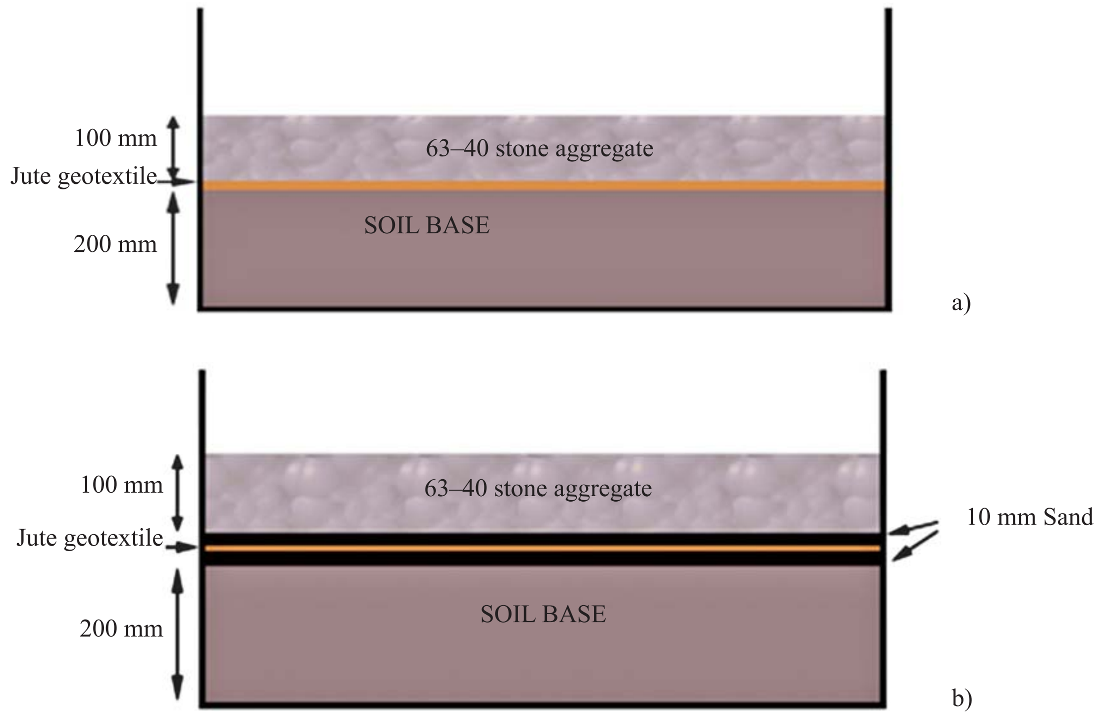


Fig.1 Laboratory model road designs: a) without sand layer, b) with sand layer

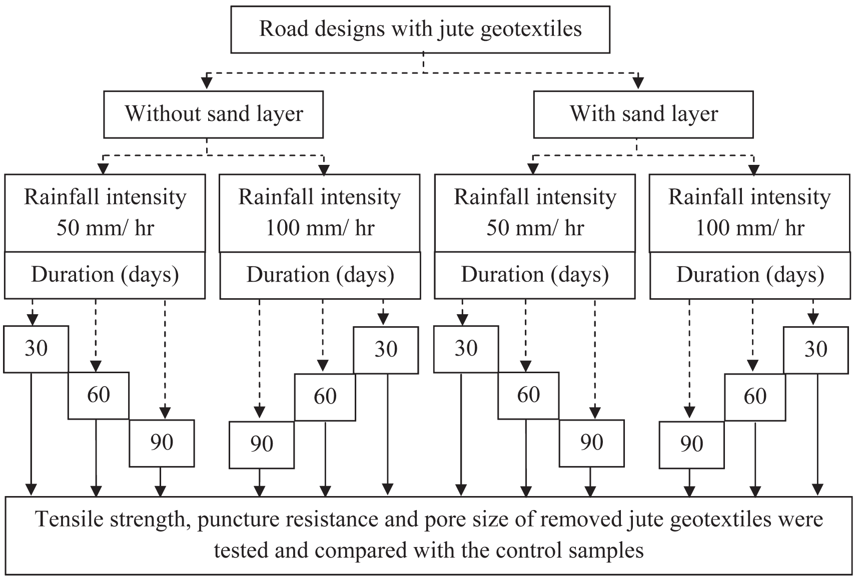


Fig.2 Experimental combination of different road design, rainfall intensity and duration

Puncture resistance tests of jute geotextiles was performed according to IS 13162-4 (1992) standards in a fabricated instrument, using 20 mm^2 samples [28]. The instrument consists of a brass cone, measuring cone and mounding clamps with water container. The brass cone has a base diameter of 50 ±0.1 mm, tapering angle of 45^o and weighs 1000±1 grams. The measuring cone has a tapering angle of 14^{o}15’, and it is used to measure the diameter of hole formed in the samples by brass cone, when it is dropped during the experiment. The mounding rings are fixed to the water container and the testing samples are mounted to these rings with a clearance of 5 mm from the water. The

a) b) c) d)

Fig.3 Jute geotextile samples removed from different road designs subjected to 100 mm/hr rainfall intensity: a) 60 days without sand layer, b) 60 days with sand layer, c) 90 days without sand layer, d) 90 days with sand layer brass cone is subjected to fall freely from the height of 500 mm, and the maximum diameter of punctured hole formed due to the fall of brass cone was measured using measuring cone (IS 13162-4: 1992). Lower the diameter of punctured hole, better the puncture resistance of geotextiles.

The pores of jute geotextiles removed from the road design are expected to be blocked with inflow soil particles, so the pore size of geotextiles was tested in "PMI Capillary flow porometer (CFP- 1100 AN)" according to ASTM D 6767:2014 standard [29].

3. Result and discussion

3.1. Tensile strength and breaking elongation

Tab.2 shows the tensile strength and breaking elongation of jute geotextiles, after their use in different unpaved road designs at different rainfall conditions for different duration. It is observed that the tensile strength and breaking elongation of jute geotextiles reduces after their usage in unpaved roads. Significant reduction in tensile strength was observed after 30 days of usage in the roads and it reduces further as the duration of usage increases (Fig.4). It is due to the significant influence of microorganisms at the initial 28 days, which deforms the OH groups and degrades C-O-C bonds in the cellulosic chain [30-31]. The jute geotextiles were found to be almost completed degraded after 90 days, as the warp yarn tensile strength was found to be only 5.4 % of its initial strength at 100 mm rainfall intensity, in road design without sand.

3.1.1. Effect of road design

It is observed that the geotextiles laid with sand layer retain tensile strength better as compared to the jute geotextiles laid without sand layer at all levels of rainfall intensity (Fig.4). It is due to the reduction in microbial activity on the jute geotextiles, when sand layer is used with the geotextiles [32-34]. Since the sand particles are free from organic content, larger in size, and have larger pore spacing, which allow the water to drain easily and keep the geotextile surface free from moisture. Dry conditions restrict the growth and action of microbes on jute geotextiles. The warp tensile strength of jute geotextiles without sand layer at 100 mm rainfall intensity was observed to be 5.4 % of its initial strength, after 90 days of usage, which is much lower as compared to the 21.8 % of initial strength of geotextiles with sand layer in the road design. Hence, the presence of sand layer in substructure helps to retain the tensile strength of geotextiles for longer durations. Similar trends were observed in weft direction tensile strength, but the rate of reduction in strength is higher in wrap direction as compared to weft direction. This is due to the higher ends/cm of warp yarn than the weft yarn density (Tab.1). At higher number of ends/cm, the number of yarns affected by microbial activity would be higher, which increases the rate of degradation. Analysis of variances (Tab.3) shows that the sand layer in the road design has a significant contribution of 34.12 % in the tensile strength retention of geotextiles. Similar trends were observed for the breaking elongation of jute geotextiles. The retention in breaking elongation is more than 75 % in all the cases.

3.1.2. Effect of rainfall intensity

As rainfall intensity increases from 50 mm/hr to 100 mm/hr, a small reduction in tensile strength was observed for both types of road designs (Fig. 4).The contribution of rainfall intensity in the tensile strength reduction is only 5.33%, according to ANOVA analysis (Tab.3). This is due to the presence of sand layer around the jute geotextiles which keeps the geotextiles dry even at increased rainfall intensity, and prevent generating suitable environment for growth and

Tab.2 Effect of rainfall intensity and road design on the tensile strength and elongation of jute geotextiles

Road design	Duration (Days)	Mean value and Retention %	Tensile strength (kN/m)				Breaking elongation (%)			
			50 mm rainfall		100 mm rainfall		50 mm rainfall		100 mm rainfall	
			Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
Control sample	0	Mean	24.75	24.5	24.75	24.5	10.5	9.2	10.5	9.2
Without sand	30	Mean (Retention%)	10.66 (43.1)	10.78 (44.0)	9.51 (38.4)	10.05 (41.0)	8.9 (84.8)	8.9 (96.7)	8.7 (82.9)	8.9 (96.7)
	60	Mean (Retention%)	6.86 (27.7)	7.18 (29.3)	5.41 (21.9)	5.88 (24.0)	8.2 (81.1)	8.5 (92.4)	8.0 (76.2)	8.2 (89.1)
	90	Mean (Retention%)	1.617 (6.5)	3.23 (13.2)	1.35 (5.4)	1.86 (7.6)	7.5 (71.4)	8.2 (89.1)	7.3 (69.5)	7.7 (83.7)
With sand	30	Mean (Retention%)	12.01 (48.5)	12.01 (49.0)	11.76 (47.5)	11.31 (46.2)	9.2 (87.6)	9.0 (97.8)	9.3 (88.6)	8.9 (96.7)
	60	Mean (Retention%)	9.07 (36.6)	9.56 (39.0)	7.91 (32.0)	8.13 (33.2)	8.8 (83.8)	8.9 (96.7)	8.6 (81.9)	8.8 (95.7)
	90	Mean (Retention%)	7.84 (31.7)	8.97 (36.6)	5.39 (21.8)	5.78 (23.6)	8.5 (81.0)	8.8 (95.7)	8.3 (79.0)	8.5 (92.4)

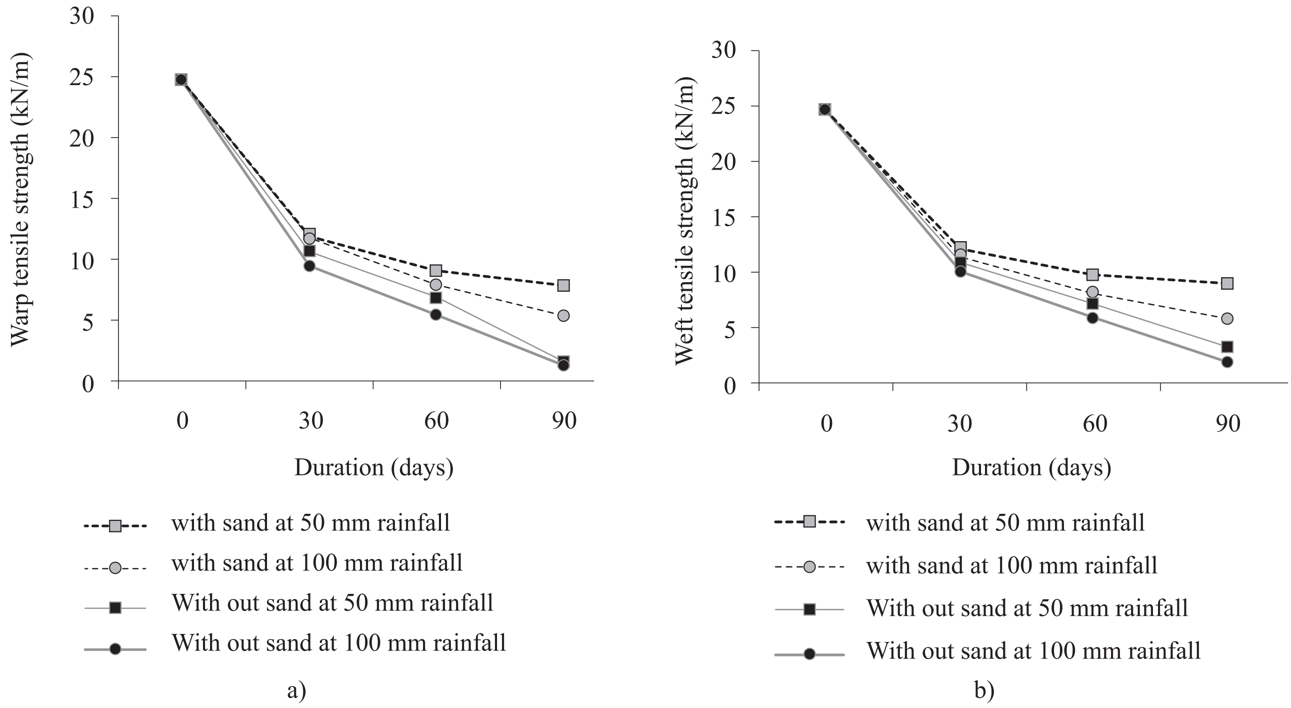


Fig.4 Effect of rainfall intensity and road design on the tensile strength of jute geotextiles; a) warp direction, b) weft direction

Tab.3 ANOVA results for the tensile strength at break of jute geotextiles

Effect	Sum of square	Degrees of free-dom	Mean square	F calcula-ted	F tabu-lated	Contribu-tion %
Sand	22971	1	22971	352	9.33	34.21
Rain	3589.26	1	3589.26	54.9	9.33	5.33
Time	73416.58	2	36708.29	562	6.93	54.61
Sand*Rain	201.26	1	201.26	3.08	9.33	-
Sand*Time	5974.75	2	2987.38	45.7	6.93	4.44
Rain*Time	421.33	2	210.66	3.22	6.93	-
Sand*Rain*Time	1063	2	532.5	8.14	6.93	-
Error	849.4	13	65.34			

Tab.4 Effect of rainfall intensity and road design on the puncture diameter and pore size of geotextiles

Road design	Duration (Days)	Puncture diameter (mm)		Pore size (μm)	
		50 mm rainfall	100 mm rainfall	50 mm rainfall	100 mm rainfall
Control sample	0	6.5	6.5	110.29	110.29
Without sand	30	16.5	18	93.54	77.31
	60	32	34.5	78.81	75.31
	90	46	50	75.89	71.37
With sand	30	12.5	13	101.86	99.9
	60	14.5	26	101.16	85.67
	90	28	37.5	100.41	81.7

action of microbes on jute geotextiles. However, at higher duration of usage of geotextiles and higher rainfall intensity, the reduction in tensile strength of geotextiles increases. The usage duration (number of days) has a contribution of 54.61 % in tensile strength reduction during ANOVA analysis. Similar trends were observed for the breaking elongation of geotextiles

3.2. Puncture resistance

Tab.4 shows the puncture diameter and pore diameter of jute geotextiles, after their use in different unpaved road designs at different rainfall intensities for different duration.

3.2.1. Effect road design

It is observed that the puncture resistance of jute geotextiles decreases (puncture diameter increases) with increased duration of usage (Fig.5). The puncture diameter of jute geotextiles at 100 mm rainfall intensity, with sand layer was observed to be 13 mm after 30 days of service, but it was observed to be 50 mm after 90 days of service without sand layer. The sand layer in the substructure of road design improves the puncture resistance of geotextiles at varying rainfall intensity.The puncture diameter of jute geotextiles at 50 mm/hr rainfall intensity, with sand layer in road design was observed to be 12.5 mm and

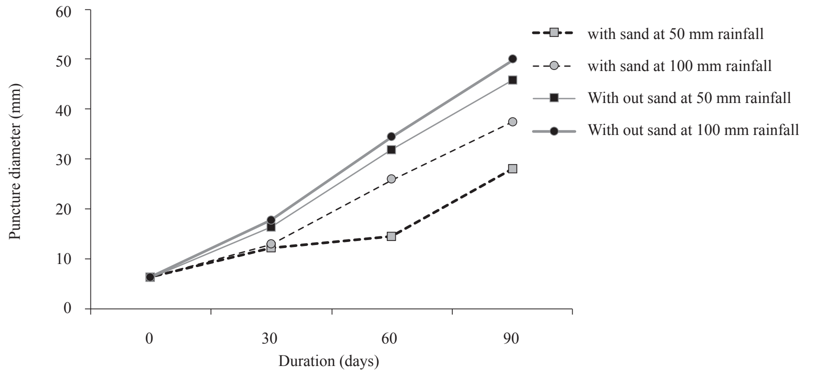
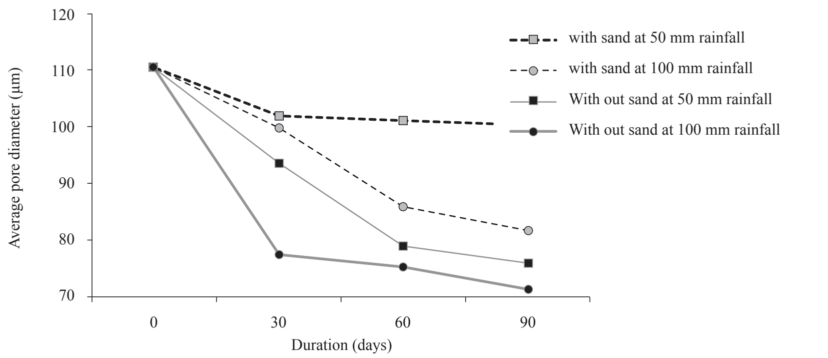


Fig.5 Effect of road design and rainfall intensity on the puncture resistance jute geotextiles

Tab.5 ANOVA results for the puncture resistance of jute geotextiles

Effect	Sum of square	Degrees of free-dom	Mean square	F calcu-lated	F tabu-lated	% Contribution
Sand	6.33	1	6.33	633	9.33	28.46
Rain	1.23	1	1.23	123	9.33	5.53
Time	24.45	2	12.22	1222	6.93	54.94
Sand*Rain	1.41	1	1.41	141	9.33	6.34
Sand*Time	1.21	2	0.60	60	6.93	2.7
Rain*Time	0.58	2	0.29	29	6.93	1.3
Sand*Rain*Time	0.31	2	0.16	16	6.93	0.72
Error	0.12	13	0.01			



Sl.6 Utjecaj cestovne konstrukcije i količine kiše na prosječnu veličinu pora na jutenom geotekstilu

28.0 mm, after usage of 30 and 90 days respectively. But it was observed to be 16.5 mm and 46.0 mm in the road design without sand layer. This is due to the reason that, presence of sand layer around the geotextiles keeps it dry and prevents degradation due to microbial activity, which is mainly responsible for the lower tensile strength and puncture resistance after use. This is also confirmed from the pore size of geotextiles, which is found to be higher in the road design with sand as compared to that design where sand is not used. Smaller pore sizes in the road design will lead to poor permittivity and transmittivity of moisture and will support microbial activity (Tab. 4). Further, the presence of sand layer acts as a cushion and protects the geotextiles from the direct impact of harsh stone edges under heavy loads during the movement of heavy traffic. It results in the reduced crepe loading and fatigue of geotextiles [23, 35].

3.2.2. Effect of rainfall intensity

Similar to tensile strength and breaking elongation, the increased rainfall intensity had a marginal influence on puncture resistance of geotextiles in both road designs (Tab.5). However, the increase in puncture diameter was found to be higher at higher duration of usage (60^{th} and 90^{th} day), because of the increased microbial activity under moist conditions leading to higher degradation of geotextiles.

3.3. Average pore size

3.3.1. Effect road design

It was observed that the average pore size of jute geotextile was highly influenced by the presence of sand layer in road design (Fig.6). The average pore diameter of the jute geotextile laid with sand layer at 50mm rainfall was observed to be 101.86 and 100.41 µm, at 30^{th} and 90^{th} days of service. But it was observed to be 93.54 and 75.89 µm when laid without sand layer at same rainfall intensity and service duration (Tab.4). The sand layer in the road design controls the flow of soil particles into the pores of jute geotextiles and avoids pore blocking. But in the road design without sand layer, the flow of soil particles into the pores will be higher, which results in faster rate of poresize reduction. Decrease in the pore size will be responsible for poor transmittivity of moisture and degradation of geotextile, as discussed earlier.

Fig. 6 Effect of road design and rainfall intensity on the average pore size of jute geotextiles

3.3.2. Effect of rainfall intensity

Rainfall intensity is also highly influencing the pore size reduction of jute geotextiles (Tab.6), due to the increased water pressure and flow rate of soil particles at higher rainfall intensity. The increased flow rate and water pressure can carry the soil particles deep into the jute geotextile structure and block its pores rapidly.

Tab.6 ANOVA results for the average pore size of geotextiles

Effect	Sum of square	Degree of freedom.	Mean square	F calcula-ted	F tabu-lated	% Contribution
Sand	2631.97	1	2631.97	28.9	7.17	39.71
Rain	1783.77	1	1783.77	19.6	7.17	26.93
Time	1798.81	2	899.40	9.87	5.18	13.56
Sand*Rain	631.87	1	631.87	6.94	7.17	-
Sand*Time	319.12	2	159.56	1.75	5.18	-
Rain*Time	211.1	2	105.55	1.16	5.18	-
Sand*Rain*Time	828.97	2	414.48	4.55	5.18	-
Error	3279.96	36	91.11			

Hence the reduction in pore size is observed to be higher at higher rainfall intensity. Further the reduction in pore size was observed to be lower on later days of service, due to the saturation in blocking of pores. The duration to reach the saturation of pore blockings varies based on the road design and the rainfall intensity. Hence in the analysis of variance, sand layer in road design contributes about 39.71 % in pore size reduction, which was followed by rainfall intensity (26.93 %) and the duration of usage (13.56 %).

4. Conclusion

By studying the influence of road design and rainfall intensity on the time dependent serviceability of 760 g/m^2 grade jute geotextiles (JGTs), it was observed that the tensile strength, breaking elongation, puncture resistance and pore size of jute geotextiles, which influence the reinforcement and drainage function of geotextiles are significantly influenced by road design, rainfall intensity and duration of usage. Average pore size was found to show marginal changes with the increase in duration of usage. Jute geotextiles were found to be completely degraded after usage of 90 days under the unpaved roads, when subjected to 100mm/hr rainfall. However, with the use of sand layer around the jute geotextile in the road design, the service life of geotextiles was found to improve. It was due to the control of microbial growth and ensuing degradation of jute fibres. Therefore using jute geotextile along with sand layer in unpaved road design can provide better serviceability at all rainfall intensities.

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