CHAPTER 12

CHARACTERISATION OF SOIL - FIBRE COMPOSITE

12.1 GENERAL

When coir geotextiles are used for the ground improvement either for strengthening subgrade or embankment, after its life period of 4 to 5 years, it may be gradually transformed into fibres of varying length due to degradation. The presence of these randomly oriented coir fibres in the soil mass may be considered similar to an admixture for stabilization. Moreover, these randomly oriented fibres in soil may reduce the drainage path during consolidation process and thereby dissipate pore pressure due to the applied load, since the water can find easy way to escape due to the random orientation of the fibres. Hence the study is also aimed to investigate the effect of discrete randomly oriented coir fibres on the performance of pavement supporting soil.

The main idea was to produce a stabilized soil-fibre matrix with enhanced properties relative to virgin soil and establishing the magnitude of inherent variations in strength and compressibility properties. The effect of fibre content and fibre length was investigated by conducting test on soils with and without coir fibres under different moisture and stress environments and to arrive at the optimum values.

Experiments were done with fibre contents up to 2.5% and length up to 20mm. Fibre contents more than 3% was not used in the study due to the difficulty of obtaining an even distribution of the fibre in the soil. Also the amount of fibre that remain in soil after degradation of coir geotextiles is not expected to be more than this value.
12.2 LABORATORY INVESTIGATIONS

12.2.1 Compaction Test

To determine the effect of reinforcing fibres on the moisture – density relationships, standard compaction tests were conducted as per Bureau of Indian Standard specifications on controlled soil (clayey silt and red soil) and soil - fibre mixtures. An even distribution of fibre and soil was achieved by consistent mixing procedure. Compaction was done with the help of an automatic compactor. Specimens were prepared by using both soils mixed with fibre contents of 0%, 0.25%, 0.5%, 1.0% and 2% by weight with different fibre lengths of 10mm, 15mm and 20mm, taking fresh samples each time. It should be noted that the soil - fibre mixes were less workable because of the fibre webbing during mixing.

12.2.2 Unconfined Compression Test

Red soil and Clayey silt soil fractions passing through 425-micron IS sieve were used for the preparation of the soil - fibre composite specimens. Fibres having length 10mm, 15mm and 20mm were mixed with soil in three proportions viz., 0.5%, 1.0% and 2.0% of dry soil by weight. Specimens were prepared at water contents corresponding to 95% of maximum dry density of the soils (dry of optimum and wet of optimum conditions). All specimens tested were of 52 mm diameter and 104 mm height. To prepare the specimens, calculated amount of soil-fibre mixture, were compacted in three equal layers. Before compacting the soil in the mould, the inside of the mould was coated with oil in order to reduce the chance of breaking of specimens during removal from the mould. The soil mixture was pressed in the mould by means of hydraulic jack. Any fibres protruding out at the top and bottom of the specimens were trimmed with scissors.
Loading was done in an AIMIL Unconfined Compression testing machine. The strain was controlled at a rate of 0.5% per minute throughout the testing programme. Peak values of stresses were noted.

12.2.3 Triaxial Shear Test

Soil - fibre mixes were prepared as in the case of UCC test. Specimens of 26mm diameter and 52mm height were prepared in split moulds. Unconsolidated undrained triaxial tests were done at confining pressures of 50 kPa, 100 kPa and 150 kPa. The shear strength parameters (cohesion and angle of internal friction) were found out.

12.2.4 Consolidation Test

Clayey silt soil passing through 425 microns was taken for the test. Dry soil was mixed with known percentage of fibre (0.5%, 1.0%, 2.0% and 3.0%) having specified lengths (10 mm and 15 mm). Water was added and mixed thoroughly to get a uniform randomly oriented saturated soil - fibre mix. The soil - fibre paste was filled in the consolidation ring. Proper care was taken while filling the soil to minimise the entrapped air.

Conventional oedometer tests were done using a standard consolidation ring of 60mm diameter and 20mm height. Readings were recorded before and after placing the load. Each load was kept for 24 hours. Load increment ratio was 1:1. Void ratio for each pressure was calculated and pressure void ratio variations were plotted to study the variations in compression index. Time settlement readings were taken at a pressure of 200 kPa to find Coefficient of consolidation by curve fitting methods.
12.3 RESULTS AND DISCUSSION

All the data obtained from the experimental investigations were analysed to study the magnitude of inherent variations in moisture content-dry density relationship, unconfined compressive strength, triaxial shear strength and compressibility characteristics of soil-fibre matrix. The effect of fibre content and aspect ratio of fibres were analysed to arrive at the optimum values of fibre content and fibre length to get maximum benefit.

12.3.1 Moisture Content Dry Density Relationship

Fig. 12.1 shows the variation of optimum moisture content with fibre content for clayey silt soil and red soil blended with coir fibres. It can be seen that, for both soil -
fibre mixes, as the fibre content increases the optimum moisture content increases irrespective of aspect ratio of fibres. The OMC of clayey silt and red soil without coir fibres was 24% and 17% respectively. Due to addition of 1% fibre the increase in OMC was 7.5%, 9.6% and 8.75% for clayey silt fibre mixes with fibres of length 10mm, 15mm and 20mm respectively. The respective increase in OMC for red soil with 1% fibre content is 10%, 15% and 14% respectively. Though the OMC increases with fibre content for all cases of fibre length considered, it was found that the rate of increase in OMC was not uniform. The maximum increase was for 15mm fibre and the minimum was for 10mm fibre.

Variation of OMC with fibre length for clayey silt and red soil are shown in Fig.12.2. It can be observed that, as the aspect ratio of the fibre increases, OMC increases to a maximum value and then shows a decreasing trend. This behaviour was identical in both soils with all fibre contents.

![Fig. 12.2 Variation of OMC with fibre length](image-url)
The variation of MDD with fibre content for clayey silt and red soil is shown in Fig. 12.3. As the fibre content increases, the maximum dry density decreases irrespective of fibre length. As can be seen from the plots, MDD decreases sharply with the addition of 0.25% of fibre and thereafter the decrease is at a low rate. For instance for clayey silt, MDD decreases to 14.8 kN/m³ from 15.2 kN/m³ with the addition of 10mm fibre and decreases to 14.7 kN/m³ with the addition of 20mm fibre. The reduction is still more in the case of red soil.

The specific gravity of the coir fibre is 1.15 and that of the soil is 2.73. As the fibre content increases, the lower density fibres replace the higher density soil grains resulting in a lower density for the soil-fibre composite.

Fig. 12.4 shows the variation of MDD with fibre length. It can be seen that the MDD decreases initially with increase in fibre length and then increases after reaching the minimum value.
Analysing the results obtained from compaction tests, it is clear that the behaviour of soil-fibre mixes in terms of OMC and MDD shows a reverse trend. It is clear that the reinforcing fibres impede the compaction process resulting in a lighter composite material. The response surfaces for OMC and MDD with fibre content and fibre length are shown in Fig. 12.5 for the two types of soils.

### 12.3.2 Unconfined Compressive Strength

Data were generated at wet of optimum and dry of optimum conditions corresponding to water contents at 95% of MDD of soils to clarify whether the variation is due to lower density and high water content or both. Results of UCC tests showing variations with fibre content for clayey silt soil are shown in Fig. 12.6.
Fig. 12.5 Response surfaces for OMC and MDD

Peak compressive strength was increased up to 2% fibre content and then showed a reduction in strength upon further increase in fibre content. This was attributed to an optimum fibre content. This behaviour was identical in both wet of optimum and dry of optimum conditions in the two soils tested.
When UCC was plotted against fibre length, the variations obtained were similar to variations with fibre content. Fig. 12.7 shows the variation of UCC with fibre length.
for red soil with 1% of fibre content. It was observed that the strength increased with fibre length up to 10mm length. Thereafter increase in length showed a reduction in UCC. Similar variations could be drawn for other fibre percentages also. Thus there exists an optimum fibre length, which gives maximum UCC for a soil.

![Graph showing variation of UCC with fibre length for red soil](image)

**Fig.12.7 Variation of UCC with fibre length for red soil**

In order to get the generalized equation for UCC of soil - fibre matrix, non-linear regression analysis was done. The analysis showed good result with $R^2$ values between 0.86 and 0.96. Making use of these equations, response surfaces showing the variation of UCC with fibre content and fibre length were drawn. Typical response surfaces are shown in Fig. 12.8. It could be easily recognised from the figures that there exist an optimum fibre content and an optimum fibre length, which give a maximum peak compressive strength. The optimum values of fibre content and fibre length along with corresponding UCC values for different cases were determined and the values are tabulated in Table 12.1.
i) Light Compaction-dry of optimum   ii) Light compaction-wet of optimum

(a) Clayey Silt

i) Heavy Compaction-dry of optimum   ii) Heavy Compaction-wet of optimum

(b) Red soil

Fig. 12.8 Response surface for UCC
Table 12.1 Optimum values of fibre content and fibre length for maximum UCC

<table>
<thead>
<tr>
<th>Soil</th>
<th>Compaction Condition</th>
<th>UCC (kN/m²)</th>
<th>Optimum Fibre Length (mm)</th>
<th>Optimum Fibre Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clayey Silt</td>
<td>Light - Dry of optimum</td>
<td>129</td>
<td>08.61</td>
<td>1.85</td>
</tr>
<tr>
<td></td>
<td>Light - Wet of optimum</td>
<td>62</td>
<td>10.00</td>
<td>1.99</td>
</tr>
<tr>
<td></td>
<td>Heavy - Dry of optimum</td>
<td>150</td>
<td>11.31</td>
<td>1.70</td>
</tr>
<tr>
<td></td>
<td>Heavy - Wet of optimum</td>
<td>104</td>
<td>11.48</td>
<td>1.66</td>
</tr>
<tr>
<td>Red Soil</td>
<td>Light - Dry of optimum</td>
<td>262</td>
<td>11.44</td>
<td>1.95</td>
</tr>
<tr>
<td></td>
<td>Light - Wet of optimum</td>
<td>186</td>
<td>10.97</td>
<td>1.90</td>
</tr>
<tr>
<td></td>
<td>Heavy - Dry of optimum</td>
<td>265</td>
<td>13.45</td>
<td>1.88</td>
</tr>
<tr>
<td></td>
<td>Heavy - Wet of optimum</td>
<td>184</td>
<td>11.76</td>
<td>1.75</td>
</tr>
</tbody>
</table>

12.3.3 Triaxial Shear Strength

Triaxial shear strength tests were conducted on specimens prepared at OMC and maximum dry density of the control soil. From the observed failure loads corresponding to three confining pressures, shear strength parameters, cohesion intercept and angle of internal friction were found out by drawing Mohr’s circles.

In order to understand the shear strength behaviour, shear strength was calculated as \( \tau = c + \sigma \tan \Phi \) for a selected value of \( \sigma = 100 \text{ kPa} \). The variations of shear strength with fibre content and fibre length are shown in Fig. 12.9 and Fig.12.10 respectively.

It can be observed that the addition of 1% of fibre having 15mm length in clayey silt soil increases the shear strength of the soil by 30%. A fibre length of 15mm showed to produce maximum shear strength. The response surfaces for triaxial shear strength are shown in Fig. 12.11. The optimum values of fibre content and fibre length, which
Fig. 12.9 Variation of shear strength with fibre content

(a) for Clayey silt soil

(b) for Red soil

Fig. 12.10 Variation of shear strength with fibre length

(a) Clayey silt

(b) Red soil
gave maximum shear strength for clayey soil and red soil were respectively 1.3% and 1.21% and the corresponding fibre length was 15.8mm and 14.98mm.

Fig. 12.11 Response surfaces for triaxial shear strength

12.3.4 Volume Change Behaviour

From the load settlement data, void ratios corresponding to each pressure were calculated and the variations were plotted to get the values of compression index. The coefficients of consolidation for each case were obtained for a pressure of 200 kN/m² using Casagrande’s logarithmic fitting method. All the data were analysed to establish the magnitude of inherent variations in the consolidation properties of fibre soil matrix.
12.3.4.1 Effect of fibre content

Fig. 12.12 shows the void ratio - log pressure (e-log p) variation for clay fibre mixture containing 10 mm length coir fibres. Four different percentage fibre content were tried viz., 0.5%, 1%, 2% and 3%. It was found that the addition of fibre resulted in decrease in voids ratio. As the applied pressure is increased, the reduction in void ratio is decreased. For example, considering soil - fibre mixture with 0.5% fibre, at a pressure of 25 kN/m², a reduction of 26% in void ratio was observed and the corresponding reduction at a pressure of 1600 kN/m² was only 13%. Considering different percentages of fibre contents, it can be seen that the rate of decrease in void ratio decreases or rather remains the same as fibre content increases. A similar trend can be observed for soil - fibre mixture with 15 mm length fibres. The plots corresponding to 1%, 2% and 3% fibres were observed to be almost parallel exhibiting the same (e-log p) variation.

![Graph showing void ratio vs. log pressure for different fibre contents.]

Fig. 12.12 (e - log p) curve for soil mixed with 10 mm fibre
12.3.4.2 Effect of fibre length

Fig.12.13 shows the comparison of behaviour of soil mixed with fibres having 10mm length and 15mm length. It is observed that at 0.5% fibre content, there is notable change in the reduction of void ratio for soil mixed with 15mm fibre, compared to soil mixed with 10mm fibre. As percentage fibre increased to 3% this variation in void ratio was only marginal.

Fig.12.14 shows the variation in void ratio at different consolidation pressures for soil-fibre mix with different fibre lengths. In general, as the length increases void ratio decreases, but for higher consolidation pressures this reduction was not much prominent.

![Fig. 12.13 Effect of fibre length on (e−log p) characteristics](image)
Fig. 12.14 Variation of void ratio with fibre length

12.3.4.3 Variation of compression index

Fig. 12.15 shows the variation of compression index (Cc) with fibre content. It can be seen that the addition of fibres in soil reduces the Cc drastically showing 58% and 24% reduction for 10mm and 15mm fibre length respectively corresponding to 0.5% fibre content. The reduction in compression index ultimately leads to the reduction in settlement. As the percentage of fibre content increases, compression index again decreases but rate of reduction in compression index is at a lower pace. At 3% fibre content the percentage reduction in Cc are 66% and 63% for 10mm fibre length and 15mm fibre length respectively. It can also be observed that the percentage reduction in compression index decreases, as the fibre length was increased.
12.3.4.4 Variation of coefficient of consolidation

The variation of coefficient of consolidation (Cv) with fibre content is presented in Fig. 12.16. The value of Cv increases from 3% to 68% as the fibre content increases from 0.5% to 3% for 10 mm fibre length. The corresponding increase in Cv with 15 mm fibres is 21% to 147%. Since the time of consolidation is inversely proportional to the coefficient of consolidation, the addition of fibre in soil reduces the time of consolidation for attaining a specified degree of consolidation. From the test results, it can be observed that, the coefficient of consolidation increases as length of fibre increases. This may be due to the fact that the drainage path becomes more accessible and continuous.
12.3.4.5 Statistical analysis

From the studies it is observed that the consolidation characteristics of soil blended with coir fibre depends on factors like length of fibre, fibre content and applied pressure. Based on the results of the present experimental investigation, a statistical analysis of the data was performed using SPSS (Statistical Package for Social Sciences). A non-linear regression analysis of the data gave rise to the following equation with $R^2$ value of 0.93.

\[ e = 1.293 - 0.168 \log p - 0.123 f - 0.13 L_f - 0.06 (\log p)^2 \quad (12.1) \]

where,

\[ e = \text{void ratio}, \]
\[ p = \text{pressure in kg/cm}^2 \ (10 \text{ kPa}), \]
\[ L_f = \text{length of fibre in cm}, \text{ and} \]
\[ f = \text{fibre content in \%}. \]

12.4 SUMMARY

Two different soils were tested at varying reinforcement - soil ratios and fibre lengths. The results of the tests proved the positive effects of adding coir fibres in enhancing the compressive strength and shear strength if an optimal reinforcement ratio and fibre length is adopted. With the addition of fibres it was observed that, the optimum moisture content of the soil generally increased and maximum dry density decreased resulting in a softer material. The coefficient of consolidation increased considerably with fibre content and the compression index decreased. Both these variations can be viewed advantageous in terms of reduction in consolidation time and the amount of settlement.