Geotechnical characteristics of polypropylene macro fibre reinforced black cotton soil treated with potassium hydroxide

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Abstract. Synthetic fibres are increasingly being used as reinforcement to help stabilise expanding soils. This work is an attempt to stabilise the black cotton soil with the reinforcement of polypropylene macro fibre in which potassium hydroxide (KOH) is utilised as an alkali activator as a contribution to this field. The KOH concentrations of 3%, 4%, and 5% with 10M were assumed, and the tests were carried out. It is also reinforced with varying percentages of polypropylene macro fibre (PP macro fibre), such as 0.3, 0.6, 0.9, 1.2, 1.5, and 1.8. California Bearing Ratio (CBR), Unconfined Compression Strength (UCS), and swell pressure experiments are carried out in the laboratory. Overall, it concluded that the addition of KOH to the soil decreased the swelling percentage of the soil by changing its mineral structure because of the presence of K ions. There was also a decrease in the shrinkage of the soil. The optimum moisture content is decreased, and the maximum dry density is increased. By reinforcing the soil with the PP macro fibre, it increased the strength of the soil.

Keywords: Polypropylene macro fibre, potassium hydroxide, CBR, UCS, SEM & XRD analysis.

1. Introduction:

Soil stabilisation can take several forms, including mechanical stabilisation, chemical stabilisation, lime stabilisation, and so on. Chemical stabilisation, as opposed to mechanical stabilisation, is known to be a short-term procedure [6,8]. However, several aspects must be addressed in the long run, such as soil mineralogy, building approach, and so on [15]. The soil is reinforced with several sorts of materials, such as fibres, sheets, geotextiles, and so on, in mechanical stabilisation [11-14]. The polypropylene macro fibre is employed as reinforcement for the KOH activated soil in this investigation. The main goal of this study is to assess the performance of the polypropylene macro fibre in the soil which is alkali activated by KOH.

The mechanical behaviour, using inclusion of polypropylene fibre, was researched by Mona Malekzadeh and Huriye Bilsel [5]. The test samples were made with MDD and OMC compacted. Water is added to the soil and settled for a day for the creation of an unreinforced sample. And following the set-up period, the fibres are added and mixed to obtain the correct distribution for strengthened samples.
The amount of fibre added is 0.5%, 0.75%, 1% to the weight of the dry unit. To check the strength and swelling characteristics, CBR, UCF, Split Tensile Strength and One Dimensional consolidation tests were conducted. As a consequence, the improvement in UCF value, cohesion value, and tensile strength was only up to 1% with the addition of fibre. The strength decreases after the first 1% increase. At 1% fibre addition, the swelling of the soil is also reduced.

M.S.Dixit and S.H.Pawar [9] sought to study the characteristics of BC soil with polypropylene fibre addition. They compared soil with various amounts of fibre added to it. The specimens with fibre reinforcement were created by manually combining dry soil, fibre, and water. By dry unit weight, the percentages of fibre applied to the soil are 0.75 percent, 1.5 percent, 2.25 percent, and 3 percent. They are also prepared at OMC’s MDD from a regular proctor test. The soaked samples were subjected to the CBR, UCS, and Undrained direct shear tests. According to the results of the test, the CBR value rose from the range of 11 percent to 47 percent by adding 2.25 percent of fibre and declined beyond that. The UCS value increased in the range of 17% to 46% by the addition of 2.25% of fibre and decreased beyond it. The same follows, with the cohesion value increasing from 2% to 21%. Hence, it concluded that a 2.25% fibre addition is an optimum mix for the design.

The fibre utilised for the enhancement of soils property for BC was polypropylene Firake Dipeeka B, Borole Seema, and Kulkarni M [7]. There were several percentages of additional fibre compared. CBR, UCS and direct shear testing with different fibre-based aspect ratios of 3mm, 4cm, and 5mm for the ranges of 0.75, 1.5, 2.25 and 3 percent. During the test, the amount of fibre to the optimal blend was found to be 2.25%.

Sandeep Singh, Tarun Sharma, and Anuj Tomar (2019) [10], Clay soil coated with a nano silica and polypropylene fibre combination was tested for strength and durability. In this research, clay soil is treated using nano silica and polypropylene fibre. The studies were carried out on soil with Nano silica and soil with PP fibre and Nano silica. Finally, it is said that the addition of both nano silica and polypropylene fibre results in a maximum UCS value.

Shiding Miao, Zhaopu Shen, Xuelian Wang, Feng Luo, Xiaoming Huang, Cundi Wei, (2017) [1], Stabilization of highly expansive black cotton soils by means of geo-polymerization. This article presents a method of geo-polymerizing black cotton soil to ascertain its potential in subgrades. CaOH₂, KOH, and cementious geo-polymers were used to stabilize the soil. KOH is found to be more effective than CaOH₂ in solidifying black cotton soil. The swelling percentage in soil has decreased from 15.7% to 2.3-4.2%. For each combination, the MDD and associated OMC were calculated. Potassium hydroxide was found to be more effective than CaOH₂ in solidifying the BCS. When CaOH₂ was added at a mass percentage of 8% or KOH was added at a mass percentage of 7%, the greatest MDDs were found. The OMC varied between 24 and 28 percent. More notably, mechanical strength increased with ageing time, reaching 16.55 MPa after 90 days of room-temperature geo-polymerization. The illitization is only observed in the KOH addition. Hence, in this study KOH is taken as the alkali activator.

2. Materials and methods:

This study used soil from the Andhra Pradesh area (kankipadu) of India. A sample was taken at a depth of 4 metres below the earth. Table 1 shows the physical characteristics that were estimated for it. This soil was stabilised with 10M KOH. To make the solution, add the appropriate amount of KOH pellets to 100ml of distilled water. The dry-volume weight of the soil was used to standardise the KOH level of 5%. For the investigation, the polypropylene macro fibre depicted in figure 1 is also used. Table 2 lists its characteristics. According to the dry weight of the soil, the fibre is utilised in various percentages of 0.3, 0.6, 0.9, 1.2, 1.5, and 1.8. The fibre is collected from the Vruksha Composites, Guntur, Andhra Pradesh, India.
Table 1. Physical properties of soil.

| Property                     | Values    |
|------------------------------|-----------|
| Silt content (%)             | 8         |
| Swell index (%)              | 60        |
| Liquid limit (%)             | 66.28     |
| Plastic limit (%)            | 46.3      |
| Plasticity Index (%)         | 19.98     |
| Optimum moisture content (%) | 21.35     |
| Maximum dry density (g/cm³)  | 1.58      |

Figure 1. Polypropylene fibre

Table 2. Physical and chemical properties of fibre used.

| Property                  | Values       |
|---------------------------|--------------|
| Colour                    | Translucent  |
| Length (mm)               | 55           |
| Diameter (mm)             | 0.85         |
| Aspect ratio              | ≥65          |
| Acid and alkali resistance| Strong       |
| Density (g/cc)            | 0.89 – 0.94  |
| Melting point (°C)        | 130 – 167    |
| Elastic modulus (Mpa)     | 4500         |
| Tensile strength (Mpa)    | 500          |

3. Test procedure and parameters studied:

CBR was developed in the 1920s and it was adopted by California in the year 1935, which is now ASTM, AASHTO, and other standard methods. It is used to evaluate the strength of soil for subgrade and base-course. This CBR test mainly indicates whether the soil is able to bear the load. Since this is now also taken as the main test for the pavements, it is adopted in this research according to ASTM D1883-14 (2014). The samples were prepared by mixing the soil with 3%, 4%, and 5% of the KOH 10M solution by dry weight. The KOH treated samples were compacted by the standard proctor test for the optimum moisture content and maximum dry density values in accordance with ASTM D698-07el (2007). The obtained results and graphs from the compaction test are shown in graphs 1 & 2.
The un-confined compression test is performed in accordance with IS code: 2720. This test is performed to assess the soil's compression strength. The samples are prepared at their optimum moisture content and maximum dry density values, as determined by the compaction test. These active specimens had diameters of 36mm and heights of 76mm, as illustrated in figures 2 and 3. The collected findings are depicted in graph 3.

**Graph 1.** Obtained optimum moisture content for different KOH percentages.

**Graph 2.** Obtained maximum dry density for different percentages of KOH.

**Graph 3.** UCS values with different KOH percentages.
Furthermore, 5% of the KOH is considered to be a standard value of the stabilisation procedure and 0.3% of the fibre is added to the soil by 0.6%, 1.2%, 1.5% and 1.8%. Compaction produced the optimal moisture content and maximum dry density, the results are illustrated in graphs 4 and 5.

**Graph 4.** Obtained optimum moisture content for different percentages of PP macro fibre.
Now the KOH has created randomly aligned polypropylene macro fibre soil sample for evaluating the CBR findings. The dirt is compressed in 56 blows in five layers. By combining 5% of KOH by dry weight and fibre at various percentages, the test specimen is created. The dry soil weight was properly blended and the optimal humidity content from the compaction test was achieved. The CBR mould has a diameter of 150mm and a depth of 175mm. Each layer is crushed using a 25.5N hammer and a 31 cm free drop. The dirt is soaked for three to four days. The results collected are shown in graph 6 below.

Graph 5. Obtained maximum dry density for different percentages of PP macro fibre.

Graph 6. CBR results obtained for different percentages of PP macro fibre with KOH activated soil.

4. Results and discussion:

The soil reacted with KOH is very dry and of low, optimised moisture content. The mineral components in the soil have changed. The black soil is usually composed of montmorillonite, however it was named montebrasite when reacted with KOH. Montmorillonite is less than 1-2, with a tougher durability of 5 to 7 (hardness based on the scale of Mohr) as montebrasite. The x-ray diffraction pictures of un-activated and activated black cotton soil are presented in Fig. 4 & 5 below.
Figure 4. XRD Graph of plain black cotton soil

Figure 5. XRD Graph of KOH activated soil.

Figure 6. Scanning electron microscope image of plain black cotton soil.
Figures 6 and 7 exhibit electron microscopic scanning pictures for ordinary black cotton and KOH soil activated. The flat soil has many layers when compared to the stabilized soils. In figure 7 almost no lamellae were observed. Agglomerations of different sized particels ranging from micrometers to nanometers are observed with alkaline content.

![Scanning electron microscope image of KOH activated soil sample](image)

**Figure 7.** Scanning electron microscope image of KOH activated soil sample

Due to the transformation of the mineral from montmorillonite to montebrasite with addition of 5 percent KOH, unconfined compressive strength is enhanced. The test findings are presented in Graphs 4 and 5, which raise the optimal moisture level and reduce the maximum dry density. The paper of Arif Ali Baig Moghal, Bhaskar C. S. Chittoori and B. Munwar Basha (2017) [2,3] explains this (Effect of fibre reinforcement on CBR behaviour of lime blended expansive soil). The length of the fibre is also investigated to influence the strength of CBR. By adding polypropylene macro fibre, the CBR value is gradually raised to 12%. The friction between the soil particles and the fibre causes an increase in the CBR value.

**5. Conclusion:**
- The addition of 5% KOH to the plain black cotton soil resulted in the formation of mineral named montebrasite with the increase in hardness and strength from the obtained XRD graphs. It formed flocculated structure observed from SEM images.
- The addition of KOH to the black cotton soil increased the UCS to 12.64 kN/m² and CBR value to 13.47. There is increase in the MDD and decrease in OMC. There is also decrease in the swelling percentage is decreased from 20% to 8-9% from free swell index due to Si-O-Si bond formation.
- The addition of polypropylene macro fibre increased OMC and decreased MDD. There is increase in the CBR value to 3 times that of the plain black cotton soil.
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