Research Article

Performance of Subgrade Soil Blended with Cement and Ethylene Vinyl Acetate

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To improve the essential properties of soil, stabilization proved to be more significant in overcoming the limitations of the desired soil. The improvement of soil properties will not only enhance the mechanical properties rather it will help in preventing dust and erosion formation. In this study, a set of tests are carried out to examine the strength characteristics of subgrade soil blended with ethylene vinyl acetate (EVA) and cement. EVA contributes almost 14% mass to the global waste, requiring bigger lands for its disposal; therefore, in order to promote a green environment and to bring an economical waste management system, an investigation of using EVA in the soil stabilization techniques is attempted. Soil specimens are investigated with and without the inclusion of EVA and cement. For this purpose, EVA was mixed with soil at a percentage level of 3, 6, and 9% whereas the cement was mixed at a percentage level of 4, 6, and 8%. To examine the combined effects of EVA and cement, the specimens were tested for compaction, direct shear, unconfined compression, triaxial, XRD, porosity, and permeability tests. All the soil samples were cured at 7, 14, and 28 days followed by the standard testing procedure. When cement was added to soil up to 4, 6, and 8% at a constant level of EVA (9%), cohesion was increased by 37, 42, and 46% while the unconfined compressive strength (UCS) was increased by 76, 81, and 84% for the same mixes. From the statistics, it clearly evident that the percentage increase caused by the addition of even 3% EVA to the cemented and uncemented soil specimens is very significant regarding cohesion and compressive strength. Porosity and permeability of soil containing both EVA (9%) and cement (8%) were decreased by 37% and 77%, respectively.

1. Introduction

A number of procedures and practices have been performed for the stabilization of subgrade of pavements like dewatering and compaction of the soil [1–3]. Such practices of stabilization may be accomplished with the help of some traditional and nontraditional stabilizers such that cement, lime, polymers [4–8], fibers and geosynthetics [9–13], and other supplementary requisite depending upon the requirement.

The utilization of chemicals in soil is a mean to improve the various characteristics of soils like shear strength, durability, and permeability, particularly of the soil that is harshly treated by the environment [14–16]. Soil may be improved traditionally by the inclusion of traditional stabilizers like fly ash, lime, and cement and such improvement demands for a certain curing time for the purpose of its strength acquiring processes. To date, various studies have been performed on the performance of soil incorporating traditional stabilizers [17, 18]. Different pozzolanic activities are involved when cement is added to the fine particles of soil, results in the enhancement of strength of soil. The stabilization by adding cement is faster and does not rely on the nature of the soil [19, 20].
Alternatively, the improvement of soil may take place by the utilization of nontraditional stabilizers like polymers, derivatives of resins and lignin, silicates, and enzymes. These methods are reasonably innovative and may be employed to weak soils for expecting its better performance [7, 21–23]. Though the performance of traditional stabilizers combined with various supplementary materials like enzymes and fibers has considerably been documented in the literature as well as employed practically [3, 24–29], however, the study related with the inclusion of traditional stabilizers combined with the nontraditional stabilizers like EVA has not been reported till now.

There are many limitations in using traditional stabilizers in soil due to which the researchers started to use nontraditional stabilizers like polymers. Polymers have the capabilities of enhancing the strength behavior of the soil [30]. Besides, polymers like EVA, styrene butadiene resin (SBR), and acrylates are currently utilized to improve various characteristics of concrete like compression strength, flexural strength, split tensile strength, and elastic modulus [31, 32]. All the mentioned materials have a wide range of advantageous characteristics like improved adhesion, stability to UV, and improved waterproofness. EVA is hydrophobic in nature and possesses moderate bonding with soil particles [33]. According to previous researchers [34], properties of peat soil may be efficiently enhanced with the inclusion of EVA in it. Such enhancement may be due to the fact that polymers have the ability of coating the soil grains that lead to the development of physical bonds. The enhancement depends upon the coating capabilities of the polymers. EVA as a low denser material than soil has many advantages. For instance, one of the studies [35] reported that amongst the huge number of polymers, EVA has the finest solarizing characteristics in soil. Besides, the degree of stability of sandy loam soil treated with poly vinyl acetate may be enhanced, i.e., improvement in aggregation [36]. One of the studies [37] reported that EVA is effective in controlling the swelling and shrinkage of soils. Both soil aggregate classes and EVA concentration play important roles in determining the magnitude of the effect on the swelling-shrinkage characteristics of the clayey soil. They concluded that it is possible to use EVA as soil stabilizer to control volume change of expansive soil in practical soil stabilization projects. Because of the mentioned characteristics, polymers are more appropriate for granular soil comparable with the fined grained soil, and as in case of granular soil, least surface area is offered for coating resulting in lowered mixing capacity. The coating of the soil particles through polymers may increase the strength properties of soil [38]. The unconfined compression strength (UCS) of soil by the addition of polymers may be enhanced after dry curing while it may be decreased after immersed curing [39].

Techniques of soil stabilization are increasing each day, and it has numerous applications in the field of geotechnical engineering. Such techniques are employed in pavements, embankments, slopes stabilization, and foundations of buildings. Strength and permeability properties of soil may be enhanced with the use of various methods for the purpose of its short comings. Amongst such techniques, stabilization of soil may be employed by using polymers which may be helpful in the improvement of its various characteristics. Although stabilization by using polymers is increasing day by day, limited studies have been carried out till now. EVA contributes almost 14% mass to the global waste, requiring bigger lands for its disposal; therefore, in order to promote a green environment and to bring an economical waste management system, an examination of using EVA in the soil stabilization techniques is attempted. Therefore, in this study, efforts have been made to investigate the combined effect of cement and EVA on strength and durability properties of subgrade soil.

2. Materials and Methods

Samples of soil were collected from local sites in Peshawar city, Pakistan. The classification of soil was found to be SW in conformance with the unified soil classification system. The collection of soil specimens was followed by drying it in the oven at 40°C for 2.5 hrs. After drying, the specimens were crumbled into smaller grains with an average size of 0.49 mm. Ordinary Portland cement (Type I) was used in combination with EVA conforming ASTM C150/C150M-19a. The properties of cement are given in Tables 1 and 2, whereas the properties of EVA are shown in Tables 3 and 4. The characteristics of soil are shown in Table 5.

2.1. Development of the Samples. A series of tests were performed on fifty-four samples; forty-five samples were tested at various fractions of cement and EVA and regarded as blended mixes, while nine samples were tested without the addition of cement or EVA and regarded as reference mixes. For maximum dry density (MDD), the samples were prepared in accordance with ASTM 698–00a; for direct shear testing, the blended soil specimens were tested followed the standards of ASTM D3080; for the unconfined test, the blended soil samples were tested in OMC-MDD condition following the standards of ASTM D1632; resilient modulus was determined in accordance with ASTM D5311-11; the porosity test of the specimens was performed in accordance with ASTM D1556, while the permeability test on the specimens was conducted in accordance with ASTM D2434-68. For the development of the entire samples, the needed water was mixed with soil on the basis of the soil’s OMC. Manual mixing of the soil samples were performed at each phase with extreme care to ensure homogenous mixing followed by compaction of the soil samples. The blended soil samples were then enfolded in polythene sheets followed by curing at 7, 14, and 28 days. The particulars of different blended mixes having various fractions of cement and EVA by

2.2. Testing Plan. The testing plan was carried out through series of tests. The tests were conducted on different soil samples having various percentages of cement and EVA by
weight. Cement was used as a traditional stabilizer while EVA was used as a nontraditional stabilizer. The entire testing plan is accomplished complying with ASTM standards as explained below.

2.2.1. Compaction Test. The standard proctor test was performed to determine compaction data of each soil sample conforming ASTM 698–00a. The air-dried sample was passed through a standard sieve number 20. The quantity of passing soil was subsequently mixed with the selected percentage of EVA followed by mixing of water. The water was mixed according to OMC followed by thorough mixing of cement. After two hours of water mixing, the blended mixtures were compacted and kept for certain period of time in moulds having dimensions of 35mm × 70mm. The percentages of cement and EVA were used on the basis of dry unit weight of soil.

2.2.2. Direct Shear Test. The samples of soil were tested for direct shear data followed the standards of ASTM D3080. The blended soil specimens were prepared in cylindrical moulds having dimensions of 61.8mm × 80mm. The samples were normally stressed at 125KPa, 250KPa, and 375KPa and charged at a strain rate of 0.12mm/min to determine the angle of friction (\(\phi\)) and cohesion (c) values.

2.2.3. Unconfined Compression Test. Unconfined compression strength (UCS) data of the soil samples was determined in OMC-MDD condition following the standards of ASTM D1632. The blended soil samples were prepared by using cylindrical moulds having dimensions of 39.1mm × 80mm. Compaction of the soil was carried out in three equalized layers followed by the soaking of samples. The soaking of samples was carried out for 24 hours in water. Soon after the completion of the curing period, the specimens were tested

### Table 1: Properties of cement.

| Standard consistency (%) | Setting behavior (min) at 22°C | Surface area (m²/kg) | Strength (N/mm²) |
|--------------------------|--------------------------------|----------------------|------------------|
|                          | Initial                        | Final                | Compressive      | Flexural         | Tensile          |
|                          |                                |                      | (days)           | (days)           | (days)           |
| 27.98                    | 124                            | 209                  | 3                | 28              | 28               |
|                          |                                |                      | 8.29             | 13.72           | 20.11            |
|                          |                                |                      |                  | 3.28            | 1.72             |

### Table 2: Compound composition of cement.

| Age composition | By chemical | By mineral |
|-----------------|-------------|------------|
| CaO             | 59.76       | 50.2       |
| Al₂O₃           | 6.45        | 6.9        |
| SiO₂            | 21.34       | 8.4        |
| Fe₂O₃           | 2.41        | 29.6       |
| SO₃             | 2.63        | 50.2       |
| MgO             | 1.79        | 6.9        |
| Na₂O            | 0.19        | 8.4        |
| K₂O             | 0.69        | 6.9        |
| LOI             | 2.03        | 8.4        |
| C₂S             | 29.6        | 8.4        |
| C₃S             | 50.2        | 8.4        |
| C₃A             | 6.9         | 8.4        |
| C₄AF            | 8.4         | 8.4        |

### Table 3: Properties of EVA.

| Material | Appearance | PH (20°C) | Ave; particle size (µm) | Glass transition temp, \(T_g\) (°C) | Viscosity (mPa.s) at 20°C | Relative density at 60°F |
|----------|------------|-----------|-------------------------|----------------------------------|--------------------------|--------------------------|
| EVA      | White powder | 9.4       | 409                     | −7.9                             | 2199                     | 0.93–0.95                |

### Table 4: Thermal properties of EVA via vicat apparatus.

| Sample | Temperature (°C) increment at each penetration |
|--------|-----------------------------------------------|
|        | 1 mm                           | 2 mm                           | 3 mm                           | 4 mm                           |
| 1      | 71.89                          | 73.12                          | 74.23                          | 75.08                          |
| 2      | 72.49                          | 72.99                          | 74.11                          | 75.10                          |
| Average| 72.19                          | 73.05                          | 74.17                          | 75.09                          |

### Table 5: Properties of soil utilized.

| Property of soil | Parameter | Value |
|-----------------|-----------|-------|
| Relative density| —         | 2.65  |
| Atterberg limits| LL        | 35.8% |
|                 | P.L       | 19.3% |
|                 | PI        | 17.9  |
|                 | USCS      | SW    |
|                 | OMC       | 15.8% |
| Compaction      | MDD       | 1.9 g/cm³ |
|                 | % Gravels | 0.0   |
|                 | % Sand    | 1.5   |
|                 | % Silt    | 63    |
|                 | % Clay    | 31.9  |
| Gradation       | \(D_{60}\) | 0.0109 mm |
|                 | \(D_{30}\) | 0.0048 mm |
|                 | \(D_{10}\) | 0.0011 mm |
| Coefficient of uniformity (\(C_u\)) | 9.7 |
| Coefficient of concavity (\(C_c\)) | 1.8 |
for UCS. During the testing procedure, the specimens were charged with a rating of 2.4 mm/min till collapsed.

2.2.4. Resilient Modulus Test. Resilient modulus is the design parameter of the subgrade soil and is a ratio of the deviator cyclic stress to the axial resilient recoverable strain; it plays a significant role in the analysis and performance of the subgrade soil [40]. Triaxial load testing of soil containing EVA and cement was carried out to assess the resilient modulus conforming ASTM D 5311-11. A mould having a height to diameter ratio of 2:1 (200 mm to 100 mm) was used. The soil sample was compacted to the desired length in 5 layers. The moisture content and the density of the soil specimens were maintained within the ±0.2% and 0.02 g/cm³ of the target values, respectively. The test was carried out for the control soil specimen (R₀), cemented soil (C₁), EVA modified soil (E₁), and EVA cemented soil (EC₁).

2.2.5. Scanning Electron Microscopy (SEM) Test. The SEM test was carried out to examine the interface interaction of soil with cement and EVA. Four soil samples (i.e., uncedmented soil, cemented soil sample, EVA-reinforced uncedmented soil sample, and EVA-reinforced cemented soil sample) with a size of 1 cm × 1 cm × 1 cm were prepared after the unconfined compression test. The samples were kept in alcohol until the test and gold coated before examination.

2.2.6. Porosity Test. Porosity is defined as the ratio of the voids to the total volume. The porosity measurement carried out in this research program was in accordance with ASTM D7263-09 and calculated as follows:

\[
\text{Porosity (\%)} = \left(1 - \frac{\text{density}_{\text{bulk}}}{\text{density}_{\text{real}}}\right) \times 100. 
\]

2.2.7. Permeability Test. Permeability is the property of a porous material that permits water to flow through its pores. Permeability of the treated samples was calculated in accordance with ASTM D2434-68 as follows:

\[
K = \frac{\gamma}{\mu} k_i, 
\]

where \(K\) is the absolute permeability (m/sec), \(\gamma\) is the specific gravity of fluid (brine), \(\mu\) is the viscosity of fluid (brine) in centipoise, \(k_i\) is the intrinsic permeability in Darcy (1Darcy = 9.87 10⁻¹⁵ m²), and \(L\) is determined as

\[
k_i = \frac{1000 \times \mu \times L}{A},
\]

where \(L\) is the length of the sample; \(A\) is the cross-sectional area of the sample; and \(m\) is the slope of the linearly fitted line between discharge and applied pressure.

3. Results and Discussion

3.1. Compaction Properties of Soil under the Influence of Cement and EVA. Figure 1 depicts the data of the soil samples with the inclusion of cement and EVA after compaction. From the obtained data, it is revealed that the maximum dry density (MDD) was achieved up to 16.9 KN/m³ in case of untreated soil, while in the soil blended with 8% of cement and 9% EVA, the MDD reached up to 16.6 KN/m³. It can be seen that there is a drop of 1.8% in the MDD of blended soil mixture, while the percentage of moisture content was found to be 16.6% in case of untreated soil mixture and 18.6% for the soil mixture blended with 8% of cement and 9% EVA.

3.2. Shear Strength Behavior of Soil under the Influence of Cement and EVA. The data of shear strength under the influence of cement and EVA are depicted in Table 7 and depicted in Figure 2. When the cement was incorporated in soil up to 4, 6, and 8% at a constant level of EVA (9%), the cohesion was enhanced from 143.07, 156.40, and 164.28 KPa to 196.71, 221.65, and 240.41 KPa, respectively.

The data revealed that the parameters of shear strength of cemented soil reinforced with EVA are increased by increasing the dosages and curing ages. The combined effect of both cement and EVA on shear strength is much marked than the influence they showed individually. The enhancement in strength of soil may be due to the fact that EVA absorbs the surrounding water in soil due to its hydrophobic nature that leads to the formation of aggregated grains of soil, and ultimately the water in the

Table 6: Notations of the blended mixtures with various fractions of cement and EVA.

| Material     | R₀ | E₂ | E₃ | E₄ | E₅ | E₆ | E₇ | E₈ | E₉ |
|--------------|----|----|----|----|----|----|----|----|----|
| % Cement     | 0  | 0  | 0  | 0  | 4  | 6  | 8  | 4  | 4  |
| % EVA        | 0  | 3  | 6  | 9  | 0  | 0  | 3  | 6  | 9  |

Table 7: Properties of blended mixtures with various fractions of cement and EVA.

| Material     | R₀ | E₂ | E₃ | E₄ | E₅ | E₆ | E₇ | E₈ | E₉ |
|--------------|----|----|----|----|----|----|----|----|----|
| % Cement     | 0  | 0  | 0  | 0  | 4  | 6  | 8  | 4  | 4  |
| % EVA        | 0  | 3  | 6  | 9  | 0  | 0  | 3  | 6  | 9  |

where \(L\) is the length of the sample; \(A\) is the cross-sectional area of the sample; and \(m\) is the slope of the linearly fitted line between discharge and applied pressure.
pores of soil grains is replaced with hydrogel. From Figure 2 it is demonstrated that for any specific content of cement, the addition of EVA beyond 3% caused slight increment in the shear strength parameters. One of the studies [35] concluded that the enhancement in shear strength is due to the coating of soil grains by polymers that leads to the development of strong physical bonds, and consequently the polar groups of polymers are absorbed on the surface of soil particles that encourage adhesion of soil grains. The development of ion exchange between the soil matrix and polymer depend upon the particular composition of polymer intended for the stabilization of soil. The data revealed that the behavior of the blended soil with respect to its parameters, cohesion (c), and angle of friction (φ) was enhanced which suggested that both cement and EVA play a significant role in the development of soil concerning shear strength. At all levels of cement and EVA, shear strength of the blended soil was progressively enhanced.

3.3. UCS of Soil under the Influence of Cement and EVA. The data of UCS of the blended soil mixtures are shown in Table 7 and graphically depicted in Figure 3, whereas the stress-strain relationship of various mixes is depicted in Figures 4–6. It can be seen from Figure 3 that when cement was incorporated in soil up to 4, 6, and 8% at constant level of EVA (9%), UCS was enhanced from 0.43, 0.63, and 0.71 N/mm² to 1.18, 1.45, and 1.78 N/mm², respectively. Nevertheless, the strength behavior of the soil blended with EVA was not much remarkable. Besides, it may be demonstrated that for any specific content of cement, the addition of EVA beyond 3% caused slight increment in the compressive strength behavior. It can easily be realized that

Table 7: Data concerning UCS and shear strength of the blended mixtures with various fractions of cement and EVA.

| Notations of soil mixtures | % Cement | % EVA | Compression strength (N/mm²) | Cohesion (KPa) | Angle of friction (deg) |
|---------------------------|----------|-------|-----------------------------|----------------|------------------------|
|                           | 7 d | 14 d | 28 d | 7 d | 14 d | 28 d | 7 d | 14 d | 28 d |
| R₀                        | 0   | 0    | 0.20 | 0.23 | 0.28 | 54.1 | 74.20 | 93.80 | 24.5 | 27.90 | 29.70 |
| E₁                        | 0   | 3    | 0.24 | 0.25 | 0.30 | 70.57 | 92.32 | 102.68 | 26.28 | 29.66 | 31.88 |
| E₂                        | 0   | 6    | 0.25 | 0.26 | 0.32 | 79.93 | 100.62 | 115.61 | 27.54 | 30.49 | 32.60 |
| E₃                        | 0   | 9    | 0.26 | 0.29 | 0.38 | 83.08 | 102.04 | 120.76 | 28.48 | 31.01 | 33.85 |
| C₁                        | 4   | 0    | 0.30 | 0.33 | 0.43 | 105.66 | 125.12 | 143.07 | 29.84 | 31.84 | 35.10 |
| C₂                        | 6   | 0    | 0.44 | 0.55 | 0.63 | 115.62 | 138.07 | 156.40 | 30.47 | 32.46 | 36.03 |
| C₃                        | 8   | 0    | 0.48 | 0.64 | 0.71 | 121.11 | 143.34 | 164.28 | 31.83 | 33.29 | 36.76 |
| EC₁                       | 4   | 3    | 0.83 | 0.92 | 1.02 | 133.42 | 158.42 | 178.11 | 32.35 | 34.12 | 38.73 |
| EC₂                       | 4   | 6    | 0.91 | 0.99 | 1.12 | 146.33 | 170.26 | 189.01 | 32.67 | 36.09 | 41.64 |
| EC₃                       | 4   | 9    | 1.01 | 1.12 | 1.18 | 155.49 | 180.49 | 198.71 | 35.07 | 38.06 | 43.72 |
| EC₄                       | 6   | 3    | 1.04 | 1.18 | 1.31 | 150.71 | 173.71 | 192.04 | 33.92 | 36.61 | 44.13 |
| EC₅                       | 6   | 6    | 1.15 | 1.28 | 1.39 | 156.30 | 181.50 | 200.62 | 34.66 | 37.44 | 45.38 |
| EC₆                       | 6   | 9    | 1.23 | 1.42 | 1.45 | 173.49 | 194.86 | 221.65 | 36.85 | 40.86 | 49.43 |
| EC₇                       | 8   | 3    | 1.29 | 1.47 | 1.58 | 182.33 | 201.04 | 224.05 | 37.59 | 41.38 | 50.05 |
| EC₈                       | 8   | 6    | 1.37 | 1.59 | 1.70 | 189.55 | 209.24 | 231.52 | 38.01 | 41.80 | 51.51 |
| EC₉                       | 8   | 9    | 1.48 | 1.66 | 1.78 | 194.84 | 215.41 | 240.41 | 39.26 | 43.46 | 53.38 |

Figure 1: Compaction properties of the soil blended with cement and EVA.
by the inclusion of EVA, improved strength characteristics might be achieved in combination with cement rather to employ it without using cement.

From Figure 4, it is noticed that the peak stress of the soil blended with EVA was increased while increasing the content of EVA up to a certain limit but further increasing the content of EVA, it was not much significant. It may also be noticed that the ductile behavior of soil treated with EVA was more marked with very small loss in post peaking strength in comparison with the untreated soil. However, by increasing EVA content beyond certain dosage, a reduction in the postpeaking stress was more marked. Moreover, Figure 4 also demonstrates that the incorporation of EVA at any stage has not influenced the initial stiffness of the blended soil in any way.

While the soil treated with cement, response of soil can be easily observed as depicted in Figure 5. While increasing the content of cement, the peak stresses were enhanced significantly and the behavior of soil was altered to more brittle and stiff one. The strain at failure was noted to be in the range of 0.59–0.64% that is quite smaller than the soil been untreated and the soil treated with EVA. Up to the peak value of axial stress, it was increased with increasing the axial strain and significantly dropped down to zero with considerable decrease in postpeaking stress.

Referring to Figure 6, the enhancement in the peak axial stresses can be seen while increasing both the contents of cement and EVA. It may also be observed that the
incorporation of cement and EVA contents have lowered the brittle response of the soil and altered it to a ductile one as compared to the soil treated with cement. Besides, the failure strain was enhanced in the range of 1.75–2.75%. Unlike the soil treated with cement, the axial stresses in the soil treated with both cement and EVA were enhanced while enhancing the axial strain followed by a gradual decrease in the postpeaking stress, and ultimately, the ductility of the soil is enhanced. Hence, it is observed from the data that the incorporation of EVA itself improved the ductility characteristics of the soil.

3.4. Resilient Modulus of Soil under the Influence of Cement and EVA. The results of resilient modulus are shown in the Figure 7. EVA cemented soil having 9% EVA and 8% cement shows high value of resilient modulus as compared to EVA modified soil and cemented soil. Resilient modulus of EVA cemented soil increases by 22% and 25% when the degree of compaction increases from 90% to 95% and 90% to 100%, respectively. The degree of compaction (DOC) influences resilient modulus as one of the basic parameter to quantify the soil effectiveness [43]. From the triaxial test confining pressure, deviator stress and the major principal stresses were used to know about the resilient modulus. Figure 7 also demonstrates that the resilient modulus was enhanced while increasing the confining pressure and degree of compaction.

3.5. Morphological Characteristics of Soil under the Influence of Cement and EVA. To examine scientifically the mechanism of interface interaction of soil with cement and EVA, SEM images have been taken. The soil structure has been modified by the addition of cement and EVA and appeared as a new soil structure as in the soil mix contained with 4% cement and 8% EVA. The modified soil structure was noticed during SEM and X-ray diffraction tests as shown in the Figures 8 and 9, respectively.

A pozzolanic reaction which leads to the formation of cementitious material is exhibited by the availability of analcite and carbonate at their respective peaks, i.e., 3.43 Å and 3.30 Å, while in stabilized soil, quartz and feldspar disappeared at peaks 3.34 and 6.14 Å, respectively.

As from the intensities graph in Figure 9 resulted from X-ray diffraction test, it is observed that in case of residual untreated soil, the feldspar (6.14 Å) and quartz (3.34 Å) exhibit the intensity peaks, while in case of soil stabilized with cement and EVA, feldspar and quartz disappeared at the intensity peaks and, at the same time, analcite (3.43 Å) and carbonate (3.30 Å) exhibited the intensity peaks. It can also be realized that stabilized soil (i.e., EC9) has high compressive strength as compared to the residual untreated soil; therefore, it can be stated that a pozzolanic reaction which leads to the formation of cementitious materials is exhibited by the availability of analcite and carbonate.

3.6. Porosity of Soil under the Influence of Cement and EVA. From Figure 10, it can be seen that percentage decrease in the porosity of the soil incorporated with EVA up to 9% was about 24%, while this decrease was about 9% when the soil was incorporated with cement up to 8%. Further reduction in the porosity (about 37%) was observed when the soil was incorporated with 8% cement and 9% EVA.

The porosity was decreased with the incorporation of cement or EVA. The soil samples incorporated with cement had more porosity as compared to soil samples incorporated with EVA. In other words, the addition of cement has caused more porosity of the mixtures as compared to the EVA alone.
Figure 7: Relationship of confining pressure, degree of compaction, and resilient modulus. (a) 100% DOC, (b) 95% DOC, and (c) 100% DOC.

Figure 8: SEM analysis of soil matrix stabilized with 4% cement and 8% EVA.
3.7. Permeability of Soil under the Influence of Cement and EVA. From Figure 11, it can be observed that the controlled mixtures have the highest permeability, wherein it was decreased up to 62% when the soil samples were incorporated with EVA alone (9%). Meanwhile, reduction in permeability occurred up to 47% when the soil was incorporated with cement alone (8%). Further reduction in permeability occurred up to 77% when both cement (8%) and EVA (9%) were incorporated in the soil. The increase in the percentages of cement and EVA caused reduction in the permeability of the mixtures. Mixtures of soil incorporated with cement had relatively lesser permeability than the soil mixtures incorporated with EVA.

3.8. Variation in Soil Mixes for All Parameters. Each soil formulation is significantly different from the other for all parameters/soil characteristics. For instance, the maximum dry density (MDD) was achieved up to 16.9 KN/m³ in case of untreated soil, while in the soil blended with 8% of cement...
and 9% EVA, the MDD reached up to 16.6 KN/m$^3$. Meanwhile, the shear strength of cemented soil reinforced with EVA was increased by increasing the dosages and curing ages. The combined effect of both cement and EVA on shear strength is much marked than the influence they showed individually. Regarding the UCS, the soil incorporated with cement up to 4, 6, and 8% and EVA up to 3% was significantly enhanced. However, the strength behavior of the soil blended with EVA is not much remarkable. Regarding resilient modulus, it has high values when soil was incorporated with 8% EVA and 8% cement as compared to EVA-modified soil and cemented soil individually. Regarding porosity, it was decreased when the soil was incorporated with EVA up to 9% and was about 24%, while this decrease was about 9% when the soil was incorporated with cement up to 8%. Further reduction in the porosity (about 37%) was observed when the soil was incorporated with 8% cement and 9% EVA. Regarding permeability, it has significantly decreased up to 62% when the soil samples were incorporated with EVA alone (9%). Meanwhile, reduction in permeability occurred up to 47% when the soil was incorporated with cement alone (8%). Further reduction in permeability occurred up to 77% when both cement (8%) and EVA (9%) were incorporated in the soil.

4. Conclusions

A set of tests were performed to study the effect of cemented and uncemented soil by the inclusion of EVA. This study is concluded as follows:

(i) By increasing the content of cement in EVA-reinforced soil; the values of MDD were reduced to some extent. Since acquiring higher values of MDD corresponds to the enhancement in strength behavior of soil, in this study, slightly lower values of MDD were observed. However, in the OMC of treated soil with cement and EVA, an increasing trend was observed.

(ii) The incorporation of cement and EVA in soil resulted in the enhancement of shear strength, UCS, and axial strain at failure. It is demonstrated that increasing the content of EVA encouraged the ductility and axial stresses of the cemented soil. At the same time, the loss in the postpeaking strength and stiffness behavior was reduced. With the inclusion of EVA, improvement in strength characteristics might be achieved in combination with cement rather to employ it without using cement.

(iii) The compressive strength behavior of cemented soil was tremendously improved by increasing the content of EVA. When cement was incorporated in the soil up to 4, 6, and 8% and EVA up to 9%, the UCS was increased from 0.43, 0.63, and 0.71 N/mm$^2$ to 1.18, 1.45, and 1.78 N/mm$^2$, respectively.

(iv) The addition of cement to the soil enhanced the stiffness and brittleness response of the soil having strain at failure, ranging from 0.59 to 0.64%, whereas the inclusion of EVA within the soil enhanced the ductility characteristics along with the

![Figure 11: Permeability of soil mixtures with the incorporation of various percentages of cement and EVA.](image-url)
improvement in postpeaking strength which indicates that the incorporation of EVA at any stage has not influenced the initial stiffness of the blended soil in any way and its failure strain ranges from 1.75 to 2.75%.

(v) The resilient modulus was increased with the increase in the confining pressure and degree of compaction; however, EVA-modified cemented soil showed high resilient modulus as compared to the other soil specimens. Resilient modulus of EVA cemented soil was increased by 22% and 25% when the degree of compaction was increased from 90% to 95% and 90% to 100%, respectively.

(vi) Porosity was decreased up to 24% when the soil was incorporated with EVA up to 9%, while this decrease was about 9% when the soil was incorporated with cement up to 8%. Further reduction in the porosity (about 37%) was observed when the soil was incorporated with 8% cement and 9% EVA. However, regarding permeability, it has significantly decreased up to 62% when the soil samples were incorporated with EVA alone (9%). Meanwhile, reduction in permeability occurred up to 47% when the soil was incorporated with cement alone (8%). Further reduction in permeability occurred up to 77% when both cement (8%) and EVA (9%) were incorporated in the soil.

The present proposed study may be concluded in a manner that the soil blended with cement and EVA acquired both the attributes of cemented soil and EVA treated soil; accordingly, it may be regarded as one of the effective practices in the improvement of soil behavior.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

On behalf of all authors, the corresponding author states that there are no conflicts of interest.

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