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Research Article

Geotechnical Investigation and Microanalysis of Black Cotton Soil Amended with Guar Gum and Polyethylene Terephlate Fibre

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Polymer-based soil stabilization has fascinated substantial interest in the field of research intending to gain a better knowledge of the anticipated soil characteristics after polymer treatment. Intricate research on the engineering performance of expansive soil which is highly challenging due to its swell and shrink nature based on variations in water regime, treated with guar gum, a biopolymer made from gum along with polyethylene terephthalate fibre, one of the most generated plastics, resulting in massive waste, is accomplished through this entire experimental investigation. Comprehensive geotechnical tests and microstructural examinations have been performed to optimize the guar gum for enhancement of soil properties and to comprehend the interactive mechanism with the soil. The biopolymer at dosages 0.5%, 1%, 1.5%, and 2% was added to the soil. Polyethylene terephthalate Fibre with an aspect ratio of 28 is used with the soil at an increment of 0.4% up to 1.6%. The optimum dosage of biopolymer was mixed with polyethylene terephthalate fibres, and its effect on geotechnical properties was carried out separately. From the experimental investigations, it is comprehended that there is a reduction of 27% and 40% in plasticity index and swelling, respectively, at an optimum dosage of 0.5% GG when compared to untreated soil. Furthermore, there is a marginal decrease of 24% in dry density, 310% increase in CBR value, and 33% reduction in compressibility of the soil treated with 0.5% GG with 1.6% PET fibre, when compared to virgin soil. The present study was conducted to improve the subgrade soil strength beneath the pavements. The usage of biopolymer and its combination with polyethylene terephthalate fibres shows that there is a considerable improvement in modifying the geotechnical properties, and its coupling effect contributes to higher California bearing ratio values. According to the outcomes of this investigation, it is proven that biopolymer and polyethylene terephthalate fibre is definitely an alternate to conventional materials. The present study was conducted to improve the subgrade soil strength beneath the pavements.

1. Introduction

Expansive soils are unreliable due to high volume change and moisture sensitivity. The well-known type of expansive soil is the Black Cotton Soil (BCS). To overcome the adverse effect of expansive soil, many researchers are consistently searching for various alternatives via ground improvement techniques. The main aim of the researchers is to stabilize the volume change behaviour, improve plasticity characteristics, and significantly enhance the strength characteristics. Several methods are adopted for improving the geotechnical properties of the expansive soil. They include methods such as mechanical, chemical, and biological stabilization. However, many chemical substances have miffed the environment. To armor the environment, a lot of research is being carried out. As a result of these research studies, biopolymers are one among which are more effective in augmenting the geotechnical properties of the soil. It is a biological method that is environmentally friendly and provides durability.

In recent years, biopolymer application for soil improvement is gaining popularity. Initially, biopolymers are used to stabilize soil against erosion for runway, roadway, and helipad construction [1]. Later, research on the interaction between soil and polymer has transcended into engineering applications. Biopolymers are an alternative to chemical methods because of their nontoxic nature and cost-saving benefit. The biopolymers commonly investigated for soil improvement are Glucan, Gellan gum [2], Xanthan gum [3], Casein, Sodium caseinate [4], Sodium Alginate [5], Agar [2], Chitosan [6], Guar gum [2], and Lignin [7]. They are commonly used in the food and medicinal industries[8, 9]. Because of their high cost, the use of polymers in engineering has often been limited, and conventional stabilizers, such as Portland cement and lime, have thus been eclipsed. Polymers have been used to manage dust at building sites, reduce sand erosion in dry and semiarid locations, and improve slope stability [1, 10–12]. Polysaccharides, for example, are biopolymers that exist naturally and are widely utilized in the food industry [9]. Because of their possible cost-saving benefits, environmentally friendly nontoxic, and free of secondary contamination, biopolymers are considered a feasible alternative to conventional chemical polymers [13, 14]. Biopolymers are carbon-neutral material that is both sustainable and renewable [15, 16]. Biopolymers are utilized to stabilize surficial soils by increasing effective cohesion and hence improving stability [17]. By breaking down into natural chemical components, biopolymers produced by natural microbes eliminate any potential toxicity issues with soil or groundwater.

There are limited works of the literature available on the usage of guar gum when compared with other biopolymers. Therefore, it is chosen for the investigation [18–21]. Also, due to the ease of availability, as India, being the largest producer and exporter of guar gum [22], its effect on improving the soil property was taken up for study. Also, it has been found to significantly improve the strength characteristics of soil [23]. Guar gum is one of the biopolymers that is a thickening and binding agent in the food industry. It is made up of D-galactose and D-mannose water-soluble polysaccharides in a 1 : 2 ratio [24]. Guar gum is polysaccharide galactomannan which is neutral nonionic [25]. It produces viscosity and thixotropic dispersion by forming chemical linkages. Based on the gel bond property, this study finds the suitability of using it on soil that may modify the geotechnical properties of the soil. Guar gum is effective in increasing dust resistance and enhancing moisture retaining capacity. PET is abbreviated as polyethylene terephthalate, the chemical name for polyester [26, 27]. This synthetic fibre consists of purified terephthalic acid (PTA) and monoethylene glycol (MEG). PET, a semicrystalline thermoplastic polymer, is one of the most prevalently used plastics in the last two decades, owing to its mechanical, chemical, and thermal qualities, as well as its low cost of manufacture [28].

The present study investigates the potential of the coupling effect of guar gum with PET fibre for enhancing the geotechnical properties of the expansive soil and understanding the interaction behaviour by performing microanalysis. By utilising energy dispersive X-ray analysis (EDX), scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FTIR), the mineralogy, microstructure, and chemical changes are better understood. The findings of the study suggest that guar gum and PET fibre combinations could be used to improve the soil's geotechnical properties in a sustainable and cost-effective manner.

2. Materials

2.1. Soil. Representative soil was collected from the GCT campus, Coimbatore, which is of Latitude N $11^{\circ}0'50.0004''$ and longitude E $76^{\circ}56'49.9992''$. It is extracted at a depth of 2 m underneath the natural ground level avoiding the topsoil. No organic content is found in the soil. The geotechnical properties of the virgin soil are listed in Table 1. As per the Indian Standard Soil Classification System, the collected soil is classified as highly compressible clay (CH). The soil shows a great tendency to swell. The sample location is shown in Figure 1(a).

2.2. Guar Gum. Guar gum (Cyamopsis tetragonoloba), a biopolymer made from the endosperm polysaccharide of the leguminous (legume) family of guar seeds, is known as a seed gum [8]. In a 1 : 2 ratio, it comprises D-galactose and D-mannose [24]. The general composition of guar gum utilized in present study is listed in Table 2. The sample image and EDX spectrum of guar gum are shown in Figures 1(b) and 2(b), respectively.

2.3. PET Fibre. PET, or polyethylene terephthalate, shown in Figure 1(c) is a synthetic fibre made of monoethylene glycol (MEG) and purified terephthalic acid (PTA). PET, a thermoplastic polymer that is semicrystalline and not biodegradable, has been produced in large quantities for the past 20 years [28]. In the present study, PET fibres were included to verify its viability to increase the CBR value of the soil. Increased CBR value reduces the pavement thickness. The interest to include PET fibres started off mainly due to the environmental concerns as plastics have become most pertinent waste posing a serious threat to the environment due to its low biodegradation. PET fibre having an aspect ratio of 28 is used in the present study. The properties of PET fibre are listed in Table 3.

3. Methods

3.1. Sample Preparation. The soil samples are dried in the oven at 105°C for 24 hr. The dry mixing process is used to prepare the guar gum mixed soil samples. Initially, 0.5%, 1%, 1.5%, and 2% of the biopolymer by weight of the clay soil are mixed with the clay soil. In a plastic tray, the biopolymer powder and soil are thoroughly blended to guarantee that

Table 1: Geotechnical properties of the virgin soil.

Sl. no.	Geotechnical property	IS method	Value	Unit
1	Initial moisture content	IS 2720: part 1: 1983	10.5	%
2	Specific gravity	IS 2720: part 3: 1980 [29]	2.75	—
3	*Atterberg's limit*			
	(a) Liquid limit	IS 2720: part 5: 1985	51	%
	(b) Plastic limit	IS 2720: part 5: 1985	27	%
	(c) Shrinkage limit	IS 2720: part 6: 1972 [30]	15	%
4	Plasticity index	IS 2720: part 5: 1985	24	—
5	Optimum moisture content	IS 2720: part 7: 1980	16	%
6	Maximum dry density	IS 2720: part 7: 1980	1.87	g/cc
7	Differential free swell test	IS 2720: part 40: 1977 [31]	60	%
8	Grain size analysis	IS 2720: part 4: 1985 [32]		
	% gravel		0	%
	% sand		33	%
	% clay		59	%
	% silt		8	%
9	IS classification	IS 1498: 1970 [33]	CH	—

(a) (b) (c)

Figure 1: (a) Location of soil sample (GCT campus) and sample image of (b) guar gum and (c) PET fibre.

there are no biopolymer lumps [36, 37]. The geotechnical tests are conducted immediately after mixing the biopolymer into the soil. Homogeneity is achieved through continuous mixing. The soil guar mixture is prepared for consistency limits, swelling, compaction, CBR, and consolidation tests. The test also involves the addition of PET fibres with soil guar mixtures. Fibres with an aspect ratio of 28 are selected and mixed with soil guar mixtures. Clay soil along with the optimum dosage of biopolymer is mixed with PET fibres at varying percentages of 0.4%, 0.8%, 1.2%, and

Table 2: General composition of guar gum [34].

Constituent	Percentage
Galactomannan	75–85
Moisture	8.0–14
Protein ($N \times 6.25$)	5.0–6.0
Fibre	2.0–3.0
Ash	0.5–1.0
Molecular weight	535.1 g/mole [35]

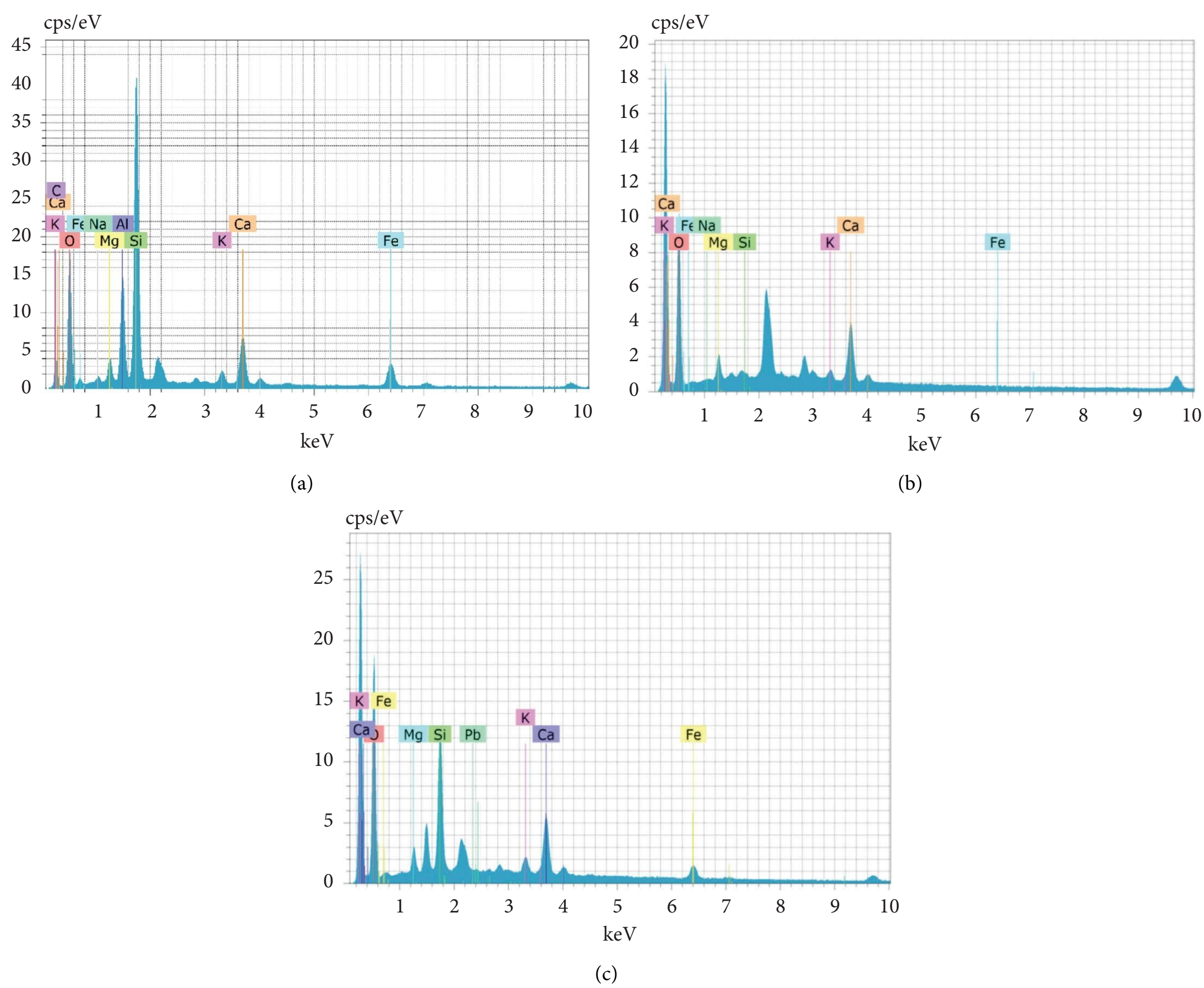

Figure 2: EDX spectrum of (a) clay, (b) biopolymer, and (c) biopolymer amended clay.

Table 3: Properties of PET fibre (source: AGL polyfil private limited, Howrah, West Bengal, India).

Property	Values
Specific gravity	1.23
Youngs modulus (E) (MPa)	2800–3100
Length (mm)	10
Diameter (mm)	0.35
Color	White
Tensile strength (MPa)	200–400

1.6%. The mixture is tested for compaction, CBR, and consolidation tests. At room temperature, the samples are mixed.

3.2. Experimental Investigation. The purpose of this research is to see how biopolymer treatment affects consistency limits, free swell index, compaction characteristics, CBR value, and consolidation characteristics. The optimal quantity of guar gum is mixed with soil-PET combination to find its suitability with it by performing compaction, CBR value, and consolidation tests.

4. Results and Discussion

The results of extensive experimental experiments were undertaken to determine the feasibility of utilizing guar gum with PET fibres to improve soil properties, and the findings are presented. Tables 4 and 5 summarize the findings of the experimental investigation.

4.1. Effect of Guar Gum on Consistency Limits. The liquid limit and plastic limit increased as the addition of biopolymer dosage increased. Thus, the plasticity index gets increased. Figure 3(a) depicts the consistency limits of soil-biopolymer mixtures. There is a steady increase in liquid limit and plastic limit values, and the increase in liquid limit values is about 2%, 9%, 16%, and 32%, respectively, and plastic limit values increase by 21%, 27%, 29%, and 46%, respectively, for 0.5%, 1.0%, 1.5%, and 2% addition of guar gum, when compared to untreated soil. The liquid and plastic limits of guar gum treated soil increase as the amount of guar gum increases due to the biopolymer's ability to create hydrogels through hydrogen bonding. Furthermore, the highly branched molecules help accelerate hydration and hydrogen bonding, resulting in a marginally higher plasticity index [21]. Similarly, Sujatha and Saisree in their paper observed an increase in liquid limit and plastic limit from 0.5% dosage of GG till 2%, while plasticity index values showed no appreciable increase [21]. Abd et al. reported an increasing trend in liquid limit and plasticity index, whereas plastic limit got decreased with the addition of carboxymethyl cellulose biopolymer in dosages of 0.5% to 5% with soft clay [38]. Also, Anandha Kumar et al. spotted an increase in plastic limit, liquid limit, and plasticity index when the concentration of guar gum was increased from 0.5% to 2% on sand-clay mixtures [23].

4.2. Effect of Guar Gum and PET Fibre on Compaction Characteristics. The density and void ratio of the soil are essential elements that determine its engineering properties. The compacted soil is a function of soil type, treatment method, compaction method, and nature of stabilizer used [21]. At first, the soil was treated with guar gum at various dosages ranging from 0.5% to 2%. OMC starts increasing as the biopolymer dosage increases, and there was a decrease in MDD marginally up to 2% dosage. Anandha Kumar et al. and Abd et al. also observed the same trend when the concentration of biopolymer increases [23, 39]. An increase in OMC is noticed, with a least and high percentage of 6% and 20%, respectively, for 0.5% and 2% increase of guar gum addition to soil, compared to virgin soil. However, when fibres were added to guar gum-treated soil, the trend was reversed with reduction in OMC of 3% and 12.5% for 0.4% and 1.6% increment in fibre content, respectively. Guar gum lowers particle friction in the soil medium [21]. At a high percentage of guar gum, viscous solution coats the soil particles and separates them, resulting in a decrease in dry density. The pores get reduced as the soil matrix gets filled with hydrogels [21, 40]. Having the optimal dosage of guar gum as 0.5%, fibres are used with increments of 0.4%. Here, OMC decreases as the fibre content increases and MDD reduces drastically. The fall was attributed to the fibre's ability to low water absorption capacity. There was a decrease in MDD with the addition of PET fibre. This was due to the loss of soil to fibre contact, attributed to the elastic response of PET inclusion during compaction along with the low specific gravity of PET fibre (1.23) compared to soil (2.75) [41]. The reduction in MDD was observed to be 3%, 6.25%, 10%, and 12.5%, respectively, for 0.5%, 1%, 1.5%, and 2% addition of guar gum to virgin clay when compared to untreated clay. Furthermore, an increased reduction of 6%, 15%, 22%, and 24%, respectively, was observed with 0.4%, 0.8%, 1.2%, and 1.6% inclusion of fibre to guar gum-treated clay, when compared to untreated clay. Similar trend in reduction of OMC and MDD is observed when polypropylene fibre was added to soft clay [42]. Figures 3(b) and 3(c) depict the effect of compaction on soil guar mixtures and soil-guar-PET combinations. The combination of the soil-guar-PET mixtures contributes to the reduction in OMC and dry density. The validity of the results is in an upright pact as revealed by the previous authors [18, 41].

4.3. Effect of Guar Gum on Differential Free Swell (DFS). Differential free swell reduces marginally by 33%, 30%, 27%, and 25%, respectively, for 0.5%, 1%, 1.5%, and 2% addition of guar gum to virgin clay when compared to untreated clay. At 0.5% dosage, there was better control of swelling. However, the swelling got controlled at further dosages when compared with virgin soil. Figure 3(d) depicts the effect of guar gum on FSI. Similar trend has been reported by Huang et al. and Soltani et al. [7, 43]. Since guar gum possesses hydrophilic property, the presence of hydroxyl groups on D-galactose and D-mannose makes them disperse in the aqueous medium [44].

4.4. Effect of Guar Gum and PET Fibre on CBR Value. Initially, the soil was treated with a varying dosage of guar gum. The guar additions from 0.5% to 2% showed improvement in the CBR value of soil. The increase in strength value may be due to filling of pore spaces that enable gel formation on the compacted soil matrix and contributes to withstand loads [21, 40]. Also, when guar gum is added to negatively charged clay particles, in the presence of water, hydration process starts resulting in the formation of hydrogels. Hydrogen bonds are created from hydrogels

Table 4: Soil mixed with guar gum.

Tests conducted	Upper limit				Lower limit				Mean			
	0.5	1	1.5	2.0	0.5	1	1.5	2.0	0.5	1.0	1.5	2.0
Liquid limit (%)	53.82	58.22	61.90	75.56	49.72	53.1	59.5	73.36	51.77	55.66	60.70	74.46
Plastic limit (%)	35.1	38.13	39.11	51.45	33.4	35.75	37.17	47.79	34.25	36.94	38.14	49.62
OMC (%)	19	20	20	22	15	16	18	18	17	18	19	20
MDD (g/cc)	1.91	1.88	1.85	1.83	1.79	1.76	1.73	1.71	1.85	1.82	1.79	1.77
Differential free swell test	42	43	45	47	38	41	43	43	40	42	44	45
CBR (%)	2.87	3.05	3.41	3.71	2.45	2.61	2.93	3.23	2.66	2.83	3.17	3.47

OMC: optimum moisture content; CBR: California bearing ratio; MDD: maximum dry density;

which coat the clay particles, thereby increasing the bonding between clay particles resulting in stiffening of clay matrix. Increase in strength value is attributed to the stiffened clay matrix [21]. Then, with the optimum dosage of biopolymer, PET fibres were added at varying increments of 0.4% till 1.6%. The strength was improved at every fibre increment. The maximum strength was attained at soil guar combination with 1.6% PET fibre with marginal improvement compared to soil guar combination with 1.2% addition. Figures 3(e) and 3(f) explain the effect of soil guar combinations and soil-guar-PET combinations. Figure 3(g) gives the schematic diagram of interaction mechanism of PET fibre and hydrogels with clay soil. The increase in CBR value for soil mixed with an optimum dosage of guar gum and PET is due to an increased frictional component of soil due to addition of fibres [45–47]. The bridge effect created by PET fibres reduces tension cracks [41]. Also, the binding action of biopolymer increases the reinforcement capacity of fibres in treated soil.

4.5. Effect of Guar Gum and PET Fibre on Consolidation Characteristics. Table 6 shows the consolidation characteristics of the soil-guar-PET combinations. It could be seen that the void ratio got reduced at 0.5% biopolymer dosage as well as with addition of optimum pet fibre. The other parameters, namely, coefficient of permeability, compression index, and coefficient of consolidation also reduced significantly when the soil was treated with optimum GG and PET fibre. The production of hydrogels and the viscous gum solution toughens the soil matrix, controlling the soil compressibility. The soil matrix is made stronger and more resistant to volume change as a result of the dehydration that occurs during the creation of the hydrogel. The hydrogel formation holds the particles intact, and the soil guar matrix sustains compression effectively. This biopolymer hydrogels can coat the surfaces of large particles and fill the pores between particles thereby reducing the permeability drastically [48]. Other researchers corroborated the decrease in soil permeability caused by the addition of biopolymer [20, 21, 49, 50]. Addition of fibres reduced the compressibility properties of soil which is in comparision to the results obtained by addition of polypropylene fibre with clay [42]. Generally, the compression index gets decreased due to the friction developed between the PET fibre and clay soil. The fibres act as reinforcing materials and act as a binding element enhancing its resistance to compression. Alternatively, there is an increase in the compression index value by 72% compared to guar gum treated clay due to inclusion of PET fibres. The reason may be associated with the increased fibre content (1.6% fibre) occupying the pores by replacing soil, making it more compressible. Also, the interaction between soil to fibre is less than soil to soil interaction [51]. It could be seen that there is only a marginal increase in CBR value with 1.6% fibre compared to 1.2% fibre inclusion.

5. Microstructural Examination

5.1. FESEM Analysis. In order to elucidate the changes in the microstructure, a series of SEM images are taken for the specimens of black cotton soil and biopolymer amended clay soil. Figure 4(a) shows the SEM image of the virgin soil containing several void spaces and a weaker soil matrix. Figure 4(b) represents the SEM image of the dry guar gum in a dispersed state. From the SEM image of soil-guar gum mixture, it is noted that the gel-like structure formed bonds between the clay particles (Figure 4(c)). Similar observation was made by previous authors [18, 21, 23]. The bonds that occur between clay and biopolymer will be hydrogen and ionic bonds [21]. Guar gum coats the soil particles and forms a bridge by means of hydrogels. On the other side, guar gum fills the voids than any other polymers due to the thick and wide bonds [23]. Micrographs show that gel particles around clay promote soil-guar aggregation (Figure 4(d)) [23]. The alteration of pore size by the reaction of biopolymer validates the strength behaviour. The bonds contribute to strength improvement and a decrease in permeability of the treated soil.

5.2. Chemical Composition by EDX. The oxides formed after the treatment of soil with biopolymer from EDX are represented in Table 7.

The EDX spectrum of untreated soil as shown in Figure 2(a) indicates the presence of silicon (Si) and aluminium (Al) as major constituents and calcium (Ca), potassium (K), sodium (Na), and iron (Fe) as minor constituents. The EDX spectrum of guar treated soil (Figure 2(c)) shows a reduction in silica (Si) and absence of alumina (Al) and sodium (Na) which may be due to hydrogel coating of clay particles.

Table 5: Soil mixed with guar gum and PET fibre.

Tests conducted	Upper limit				Lower limit				Mean			
	0.5 GG + 0.4 PF	0.5 GG + 0.8 PF	0.5 GG + 1.2 PF	0.5 GG + 1.6 PF	0.5 GG + 0.4 PF	0.5 GG + 0.8 PF	0.5 GG + 1.2 PF	0.5 GG + 1.6 PF	0.5 GG + 0.4 PF	0.5 GG + 0.8 PF	0.5 GG + 1.2 PF	0.5 GG + 1.6 PF
OMC (%)	16.5	16.4	16	15.6	14.5	13.6	13	12.4	15.5	15	14.5	14
MDD (g/cc)	1.82	1.67	1.52	1.49	1.7	1.51	1.4	1.35	1.76	1.59	1.46	1.42
CBR (%)	3.24	3.61	6.74	6.97	2.86	3.13	6.2	6.41	3.05	3.37	6.47	6.69

GG: guar gum; PF: PET fibre.

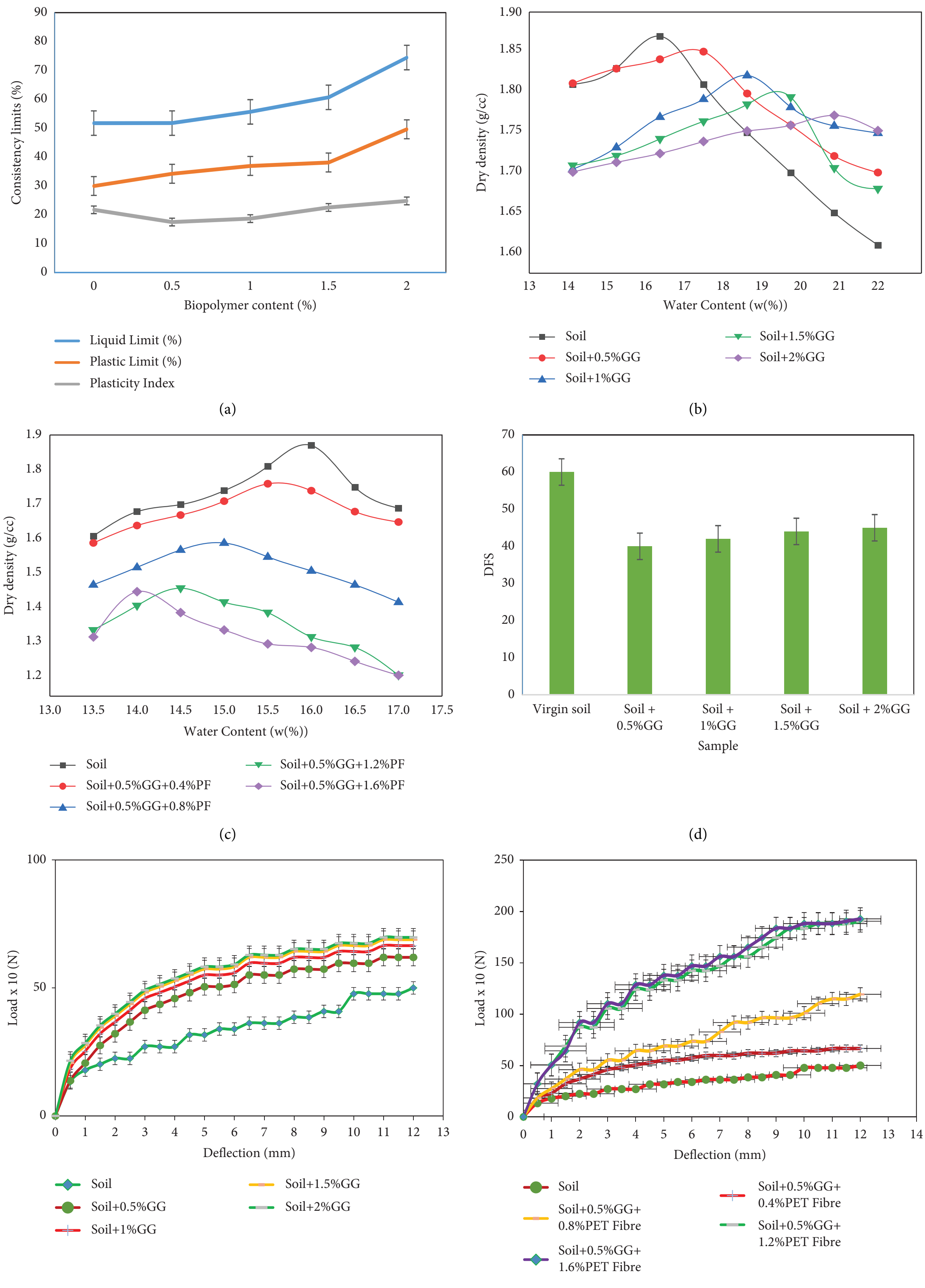

Figure 3: Continued.

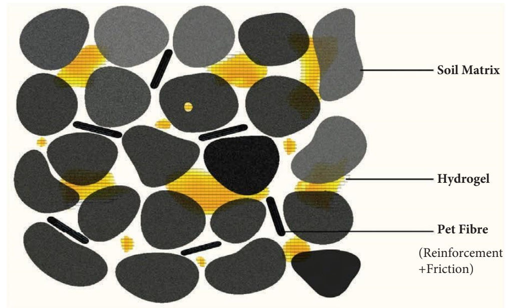

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Figure 3: (a) Consistency limits of soil treated with guar gum, (b) compaction characteristics of soil treated with guar gum, (c) compaction characteristics of soil treated with guar gum and PET fibres, (d) effect of guar gum on differential free swell test, (e) CBR curves of soil treated with guar gum, (f) CBR curves of soil treated with guar gum and PET fibres, and (g) interaction mechanism of pet fibre and hydrogel with clay.

Table 6: Consolidation characteristics of soil-guar-PET mixtures.

Sl. no.	Sample	Void ratio	Coefficient of permeability (cm/sec)	Coefficient of consolidation (cm^2/min)	Compression index
1	Virgin soil	0.563	4.70×10^{-7}	0.0409	0.083
2	Soil + 0.5% GG	0.132	2.13×10^{-7}	0.0275	0.019
3	Soil + 0.5% GG + 1.6% PET fibre	0.177	1.39×10^{-8}	0.0210	0.069

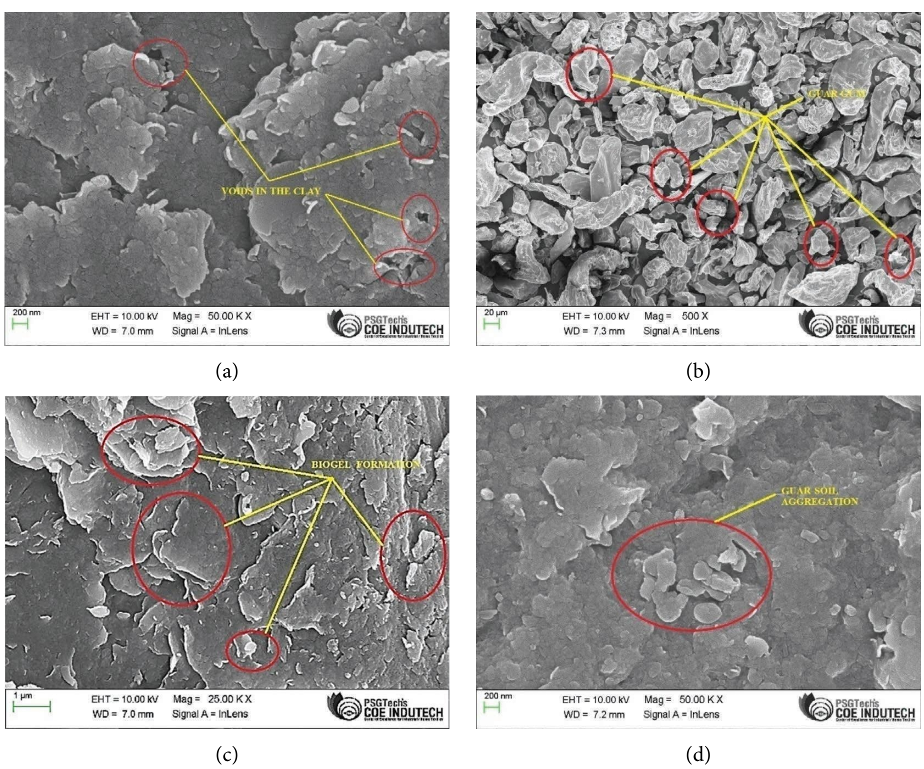

Figure 4: SEM image of the (a) virgin soil containing pores, (b) guar gum, (c) bio-gel formation with 7 days curing, and (d) soil-guar aggregation.

5.3. FTIR Spectroscopic Studies. The FTIR analyses of expansive clay, biopolymer, and soil-guar mix are shown in Figure 5. The frequency ranges are measured as wave numbers that range over 4000 to 500 cm^{-1}. A considerable variation in the bands of the FTIR spectrum of clay soil and biopolymer treated clay is observed. The peak at

Table 7: Oxide concentration of biopolymer amended clay.

Oxides	Composition (%)
SiO_2	40.87
CaO	26.37
MgO	5.34
K_2O	3.68
FeO	14.82

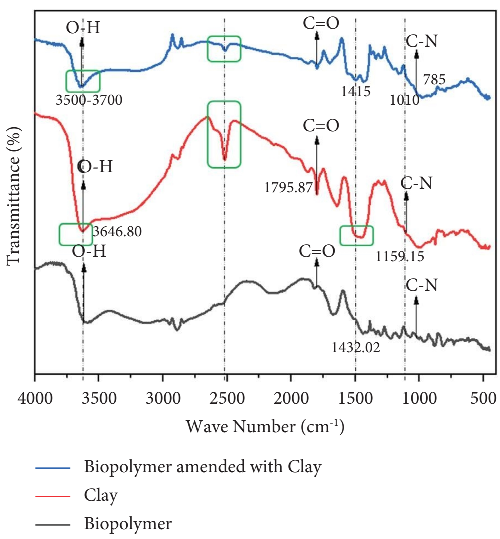

Figure 5: FTIR analyses of soil guar mixtures.

3646.80 cm^{-1} corresponds to O-H stretching due to alcohols. The peak at 1795.87 cm^{-1} indicates C=O stretching due to acid halides. The peak at 1159.15cm^{-1} corresponds to C-N stretching due to amine. The peak at 1432.02 cm^{-1} represents O-H bending due to carboxylic acid [52]. In the FTIR spectrum of biopolymer amended clay, the appearance of O-H^- stretching vibrations of the structural hydroxyl groups at 3500 to 3700 cm^{-1} becomes sharper. The increased width of the bands at 1415 and 1558 cm^{-1} reveals the amendments of guar gum with soil [53]. The decrease in sharpness at 1010 cm^{-1} with the addition of guar gum is due to the replacement of clay present in the soil. The presence of quartz is indicated by the peak at 785 cm^{-1} [54]. Overall, it is evident from the FTIR analyses that remarkable deviation in the ions and elements is responsible for the modification in the geotechnical properties of the clay treated with guar mixtures.

6. Conclusions

A significant improvement achieved in the soil-guar-PET mixtures shows good resistance against great loads. The investigation yielded the following conclusions:

(i) The optimum dosage of guar gum was found to be 0.5% based on the plasticity index, compaction characteristics, and differential free swell index.

(ii) There was an increase in OMC when soil is treated with guar gum, while the treated soil's MDD decreased marginally from 1.87 g/cc to 1.85 g/cc at 0.5% dosage to 1.7 g/cc at 2% dosage. When the soil was treated with guar gum and PET fibre combinations, it was also seen that OMC decreased and MDD decreased significantly.

(iii) When the soil was treated with guar gum at a dose of 0.5%, the swelling was reduced by around 33%. At other dosages, the swelling significantly decreased, but the dosage at 0.5% was determined to be beneficial.

(iv) CBR for soil blended with guar gum exhibits a minor increase in strength at all dosages, whereas CBR exhibits a markedly increasing trend as the fibre content rises. Clay soil that has been blended with 1.6% recycled PET fibre and 0.5% guar gum exhibits strength improvements of up to 310%. The development of strong hydrogen and ionic linkages between the biopolymer and charged clay particles is what gives the material more strength.

(v) The void ratio of the soil treated with guar gum was greatly reduced by 76% and the hence permeability of the soil treated with guar PET mixtures also decreased. This is because the guar gum occupied the voids. In addition, the compression index of soil got reduced by 77% when treated with biopolymer.

(vi) Detailed microanalysis confirmed that there were changes in the microstructure that enhanced strength and reduced the swelling of soil guar mixtures.

Guar gum with its excellent bonding properties due to formation of hydro gels stiffens the clay matrix. Inclusion of PET fibres to the stiffened clay matrix reinforces the clay matrix, effectively improving the soil strength. The outcomes of the present study significantly contribute to sustainability in geotechnical application especially for improving subgrade soil strength.

Data Availability

Data are available on request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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