Geomechanics and Engineering, *Vol. 5, No. 4 (2013) 331-342*
DOI: http://dx.doi.org/10.12989/gae.2013.5.4.331

Behavior of geotextile reinforced flyash + clay-mix by laboratory evaluation

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(Received May 10, 2012, Revised February 26, 2013, Accepted April 02, 2013)

Abstract. The major factors that control the performance of reinforced soil structures is the interaction between the soil and the reinforcement. Thus it is necessary to obtain the accurate bond parameters to be used in the design of these structures. To evaluate the behavior of flyash + clay soil reinforced with a woven geotextile, 36 Unconsolidated-Undrained (*UU*) and 12 reinforced Consolidated–Undrainrained (*CU*) triaxial compression tests were conducted. The moisture content of soil during remolding, confining pressures and arrangement of geotextile layers were all varied so that the behavior of the sample could be examined. The stress strain patterns, drainage, modulus of deformation, effect of confinement pressures, effects of moisture content have been evaluated. The impact of moisture content in flyash + clay backfills on critical shear parameters was also studied to recommend placement moisture for compaction to *MDD*. The results indicate that geotextile reinforced flyash + clay backfill might be a viable alternative in reinforced soil structures if good-quality granular backfill material is not readily available.

Keywords: geotextiles; flyash; clay; shear parameters; triaxial tests

1. Introduction

The national highway plan in India for next decade focuses on infrastructure projects, which require massive construction. The major component of which will be embankments, flyover and other retaining structures. The widely adopt *BS* code specifies sand as backfill, which may not be available at all site locations. All such structures, by present trends indicate need for alternative fill; hence a detail *R&D* to adopt regionally available top *CH* soils and industrial byproducts such as flyash, slag etc. Also strict environmental regulations on dust nuisance involved with flyash require adequate control. Availability and utilization of stabilized flyash, strength improvement of regional *CH* soils and safety against poor compaction control is the need at remote sites, for which geofabric reinforced embankment technology is one of the economical options. Low tensile strength is the main limitation to soil structure stability in many of poor draining soils. By reinforcing the soil with geosynthetics this problem is somewhat overcome. One of the most common geosynthetic materials used to reinforce such soils are geogrids in majority.

Several laboratorial and theoretical investigations have been conducted in this field, most of

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http://www.techno-press.org/?journal=gae&subpage=7 ISSN: 2005-307X (Print), 2092-6219 (Online)

which are related to granular soils reinforced with geosynthetics. Only limited studies have been reported concerning cohesive soils reinforced with geotextiles. This necessitates further studies of engineering design parameters using geotextile reinforced composite backfill mix (soils and industrial byproducts) from literature and laboratory investigations.

Examples of research involving geotextile-cohesive soil interfaces, giving a comprehensive review of the experimental and analytical studies which focused on the behavior of reinforced cohesive soil can be found in the works of Saxena and Budiman (1985), Eigenbrod and Locker (1987), Fourie and Fabian (1987), Williams and Houlihan (1987), Lauwers (1991), and Zornberg and Mitchell (1994). Lafleur *et al*. (1987) used a series of direct shear tests on highly plastic cohesive soil to evaluate and compare the behavior of woven and non-woven geotextiles on the behavior of clay. Mahmood and Zakaria (2000) concluded from the results of the shear box tests that the coefficient of friction of geotextile/organic clay interfaces reduces with the increase of normal stress and increases with the increase tensile strength of the geotextile. Ingold (1979) used a triaxial apparatus to conduct research on reinforced cohesive soils. Fabian and Fourie (1986) defined the effect of the permeability of the reinforcing material on the undrained strength of reinforced clay by conducting *UU* triaxial test on clay reinforced by materials with different values of permeability. Krishnaswamy and Srinivasula Reddy (1988) reported the influence of the distance between the reinforced materials as well as moisture content of the sample by using undrained triaxial experiments on silty clay reinforced with a geotextile. Indraratna *et al*. (1991) studied the behavior of reinforced and unreinforced soft silty clays through *UU* triaxial test. Non-woven and woven geotextiles were used in that study. The behavior of reinforced clay was examined in triaxial compression tests under both static and cyclic loading conditions by Unnikrishnan *et al*. (2002). Other studies in this field were reported by Athanasopoulos (1996), Kolias *et al.* (2005), Lekha and Kavitha (2006), Tang *et al.* (2007), Sachan and Penumadu (2007), Wang *et al.* (2007), Prashant and Penumad (2007), Houston *et al.* (2008), Kim *et al.* (2008), Subaida *et al.* (2009), and Noorzad and Mirmoradi (2010). These findings are also consistent with the finite element works of Burd and Brocklehurst (1990) and Burd and Brocklehurst (1992), who performed analytical studies on geotextile/soil interfaces and who concluded that the shear strength of soil-geotextile interfaces increases with the increase of the fabrics tensile strength. Bouazza *et al.* (1990) studied friction characteristics of polypropylene reinforcing straps in various fill including flyash. However more work needs to be done in this direction to further validate their conclusion for soil backfills in Indian environment conditions involving massive use in infrastructure development.

In the present study, the mechanical and stress–strain behavior of cohesive soil + fly ash reinforced with woven multifilament polyester geotextile has been evaluated for the first time from a different perspective. The behavior of such composite soil mix is affected by the moisture content and its reinforcing pattern. Accordingly a research program was carried out to study the shear parameters, modulus E, strain at failure ε_f, and peak strength of geotextile/soil. A series of triaxial tests were performed in the laboratory for this purpose. Pulverized *CH* (Highly Cohesive) type of soil and flyash was used in these tests, along with woven *PET* (Polyester) geotextile with high tensile strengths. Cohesive soils mixed with flyash may also have a wide range of plasticity indices. An optimum proportion of 20% *CH* clay and 80% flyash mix were adopted, from studies by Desai (2007). The addition of clay in this optimum proportion is proposed to take care of air pollution control arising during construction near towns and cities. Also it gives adequate cohesion at *OMC*, low *PI*, and high shear parameters, which is most desirable for any fill material. The objective was to study the effects of varying moisture content on unreinforced and reinforced shear parameters of such system. This knowledge would provide a better understanding of the stress – strain, influence of variation of moisture content and behavior of *PET* geotextile with composite soil (80F + 20C) on shear parameters, modulus E, strain at failure ε_f, and peak strength which ultimately contribute to the design of reinforced earth structures.

2. Testing program

To investigate the effects of varying soil parameters on the mechanical behavior of unreinforced and reinforced cohesive soils + flyash (80F + 20C), a total of 36 *UU* and 12 reinforced *CU* triaxial tests were performed. All the experiments were conducted on a sample of diameter 38 mm and height 76 mm. The procedures for specimen preparation and testing were standardized to achieve consistency in the test results. During the experiments, some of the tests were repeated to ascertain the accuracy of the results or until consistent results was obtained.

The different parameters that were varied during the experiments are:

- Three different moisture contents; two percent below the optimum moisture content, optimum moisture content and two percent above the optimum moisture content (at standard proctor compaction) for *UU* triaxial test.
- *PET* type geotextiles for reinforced *CU* triaxial test at *OMC* – 2% only.
- Relative compactions (95% of the standard compaction).
- Three different confining pressures (σ_1 = 50 kPa, σ_2 = 150 kPa and σ_3 = 250 kPa).
- The number of geotextile layers, illustrated in Fig. 1, for CU traixial test.
- All testing was conducted with a controlled strain rate of 1.2 mm per minute for the *UU* test and 0.048 mm per minute for the *CU* triaxial tests

2.1 Materials used

Clay soils from Magdulla and flyash from Ukai Thermal Power Plant of Surat district in South Gujarat in the proportion 80% Flyash + 20 % Clay were used. Their engineering properties were determined by testing as per relevant *IS* code of practices. Standard proctor test was conducted and

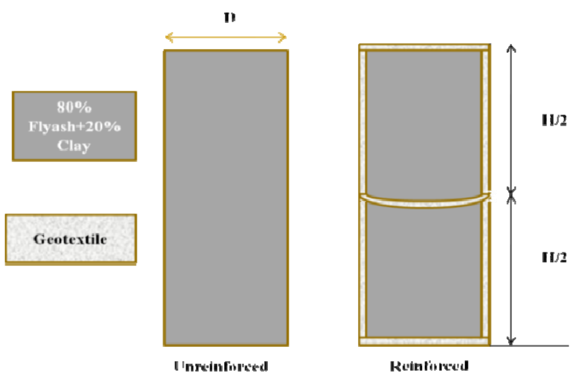

Fig. 1 The arrangement of geotextile in different samples

the results are as shown in Fig. 2. The physical and compaction properties of the mix; chemical properties of flyash are provided in Table 1A. Polyester geotextile as reinforcement was used in the testing program. The physical and mechanical properties of the geotextile are furnished in Table 1B, as provided by the respective manufacturing company.

3. Preparation of the samples

The preparation of the soil sample is of great importance for laboratorial research. The preparation of the different specimens will be outlined in this section. Initially, the water content of the soils was determined so that the amount of additional water, needed to achieve the desired water content for testing, could be determined. The soils were mixed with water and placed within double layered plastic bags and sealed for three days to achieve uniform water content within the soil mass. Moisture content was also determined before and after three days, which was found to

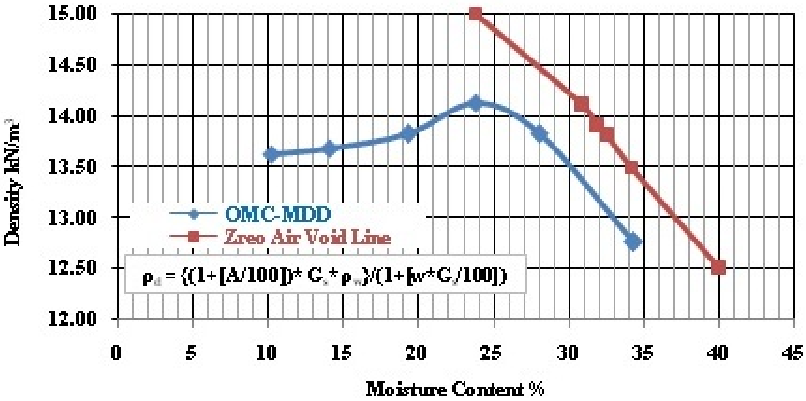

Fig. 2 Moisture density relationship for 80F + 20C proportion

Table 1A Properties of soil & fly-ash

Test	Physical properties 80 % Fly-ash + 20 % Soil		Chemical properties of flyash %	
Particle size analysis	Gravel	0	SiO_2	40.20
	Sand	4	Al_2O_3	26.82
	Silt + Clay	96	Fe_2O_3	9.30
Specific gravity	2.45		TiO_2	1.0
Liquid limit	41		CaO	11.84
Plastic limit	35		MgO	1.72
Plasticity index	6		Na_2O	0.964
Standard proctor test	*MDD* (gms/cc)	1.412	K_2O	0.565
	OMC (%)	23.74%	SO_3	1.19
Swelling pressure	Non – swelling		LOI	3.06

Table 1B Properties of *GWF PET 100-50* Geotextiles*

Property		Test method	Spec.	Test result
Physical properties				
Mass per unit area		*ASTM D 5261*	> 275 g/m^2	304
Mechanical properties				
Tensile strength	Warp**	*ASTM D 4595*	> 100 kN/m	105
	Weft**		> 50 kN/m	55
Elongation at specified tensile strength	Warp	*ASTM D 4595*	< 12 %	7
	Weft		< 12%	6
Trapezoid tear strength	Warp	*ASTM D 4533*	> 1100 N	1778
	Weft		> 1200 N	1470
Index puncture strength		*ASTM D 4833*	> 600 N	941
Hydraulic properties				
Apparent opening size		*ASTM D 4751*	< 150 microns	< 150 microns
Water flow rate		*ASTM D 4491*	> 30 l/m^2/s	35

*Manufacture by Garware Ropes Limited Pune, *PET* = Polyester (polyethylene therapthalate); *GWF* = Geotextile Woven Fabric,

**Weft and warp are terms for the threads used in weaving and are the basic constituents of all textiles. The weft is the crosswise threads on a loom over and under which other threads are passed to make cloth (cross machine direction *CMD*). The warp is the threads that are passed over and under the weft (Machine Direction *MD*).

be very close to the target moisture content. A variation of less than 2% in moisture content was observed in the samples.

The construction of the sample was done in a mould of diameter 55 mm and the height 100 mm. The sample was prepared in three equal layers. A static compaction method was applied to the soil layers as reported by Unnikrishnan *et al.* (2002). In order to obtain a sample with a diameter of 38 mm and a height of 76 mm, a hydraulic jack penetrated statically into the mold. To construct the reinforced sample, knowing how many reinforced layers are needed, the unreinforced sample is cut by a narrow saw wire and the reinforcing material is placed. This method of making reinforced samples was reported by Ingold and Miller (1983). The arrangement of different layer of geotextile (say one, two and three) was studied by Noorzad and Mirmoradi (2010). But considering a better drainage option in cohesive soil + flyash mix, special arrangement as shown in Figs. 1 and 3 was conducted. This type of arrangement has not yet been evaluated for soil reinforced with geotextile layers.

4. Results and discussions

The $UU_{Unreinforced}$ traixial test samples, with *OMC+2%, OMC, OMC-2%* and 95% *MDD*, at 1.5 mm per min strain rate; and $CU_{Reinforced}$ traixial test samples, with *OMC-2%* and 95% *MDD*, at 0.048 mm per min; at cell pressures of 50 kPa, 150 kPa and 250 kPa were performed. The corresponding stress strain curves are shown in Figs.4a to c. The results of stress strain curves for

Fig. 3 Photograph of laboratory triaxial test

Table 2 Shear parameters at variable moisture content and fixed density with strain at failure

Variable moisture content	Cohesion C (kPa)	Angle of internal friction Φ (degree)	Strain at failure ε_f %
$(OMC+2)_{Unreinforced}$	57	30	5 to 10
$(OMC)_{Unreinforced}$	68	34	3 to 8
$(OMC-2)_{Unreinforced}$	72	36	5 to 10
$(OMC-2)_{Reinforced}$	80	37	3 to 5

$UU_{Unreinforced}$ and $CU_{Reinforced}$ traixial tests at different moisture content, modulus E, strain at failure ε_f and peak strength (S_p) for 50 kPa, 150 kPa and 250 kPa cell pressure respectively are shown in Table 3. The values of cohesion C and angle of internal friction Φ, found out from modified failure envelope of traixial test is presented in Table 2.

The peak strength ratio (S_R) is the ratio of the peak strength of the reinforced samples to that of the unreinforced samples. It was observed that stress–strain behavior of soil improved with inclusion of geotextile layer. The stress–strain curves for $UU_{Unreinforced}$ and $CU_{Reinforced}$ for a relative compaction of 95% and the confining pressure 250 kPa are shown in Fig. 5. The curves provide evidence of an improvement in the mechanical properties of 80F + 20C soil samples with reinforcement to no reinforcement. This was also reported by Noorzad and Mirmoradi (2010). One possible explanation for such a behavior could be that the geotextile layers intercept the failure plane within the specimen, distributing the stresses evenly within the soil and hence, increasing the overall strength of the reinforced soil. Fig. 5 is a stress–strain diagram obtained by triaxial test. The results provide evidence that the reinforcement has improved the strength properties of the 80F + 20C soil specimen. By reinforcing the sample the peak strength increases. It was also found that for low strains, almost below 3%, the reinforcement does not considerably influence the stress–strain behavior of the samples (Figs. 4(a) to (c), Vashi 2011); this was observed in all triaxial tests. These results further indicate that at low strains, in which displacements and stresses along the soil–geotextile interface are low, the effects of the geotextile are negligible. Only at higher strains, influence of geotextile layer on the soil strength is appreciable.

Also as illustrated in Fig. 5, the reinforced samples have higher peak strength in comparison to

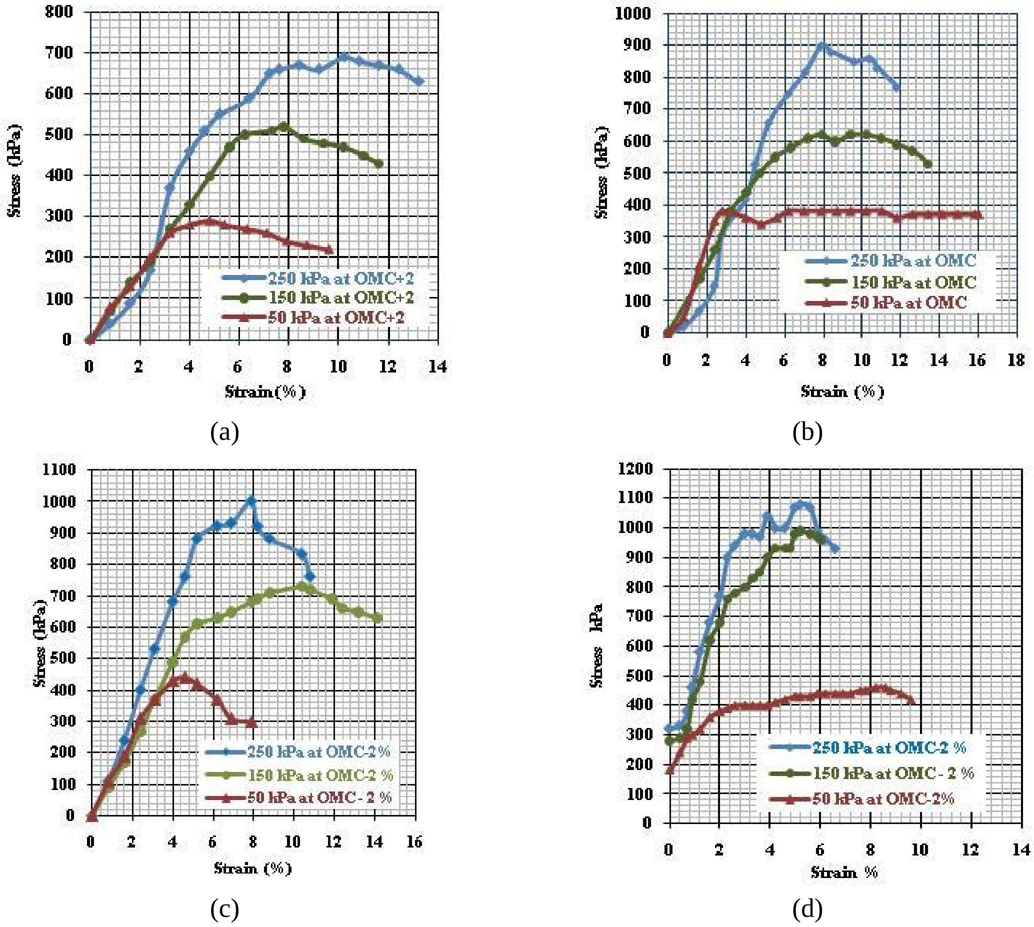

Fig. 4 (a) Stress vs strain for $UU_{Unreinforced}$ at $OMC + 2\%$; (b) Stress vs strain for $UU_{Unreinforced}$ at OMC; (c) Stress vs strain for $UU_{Unreinforced}$ at $OMC - 2\%$; (d) Stress vs strain for $CU_{Reinforced}$ at $OMC - 2\%$

unreinforced soil, as the moisture content decreases, peak strength increases further. Reinforced samples behave more ductile than unreinforced samples, this is due to the geotextile that influences the ductility of the reinforced sample. Another reason is geotextile reinforcing prevents shear band development in the samples, which is the main cause of strength loss after the peak strength in unreinforced soil (80F + 20C) samples.

The influence of the moisture content on the behavior of 80F + 20C samples of soil is shown in Figs. 6 and 7. As the moisture increases, the peak strength decreases and the strain at failure increases. This phenomenon can be explained according to the structure of cohesive soil. Studies of compacted soils at the micro level have shown that soils compacted on the dry side of optimum moisture content have a flocculent structural arrangement of particles. On the wet side of optimum moisture content, the structure is dispersed. Samples compacted dry of optimum tend to be more rigid and stronger than samples compacted wet of optimum. This change in behavior can be clearly seen in the results of the present work.

Table 3 Shear parameters at variable moisture content and fixed density with strain at failure

Condition	Particulars	Cell pressure (kPa)		
		50	150	250
$UU_{Unreinforced}$ at $OMC+2\%$	Modulus E (kPa)	8,750	9,286	10,938
	Strain at failure ε_f (%)	4.8	10.0	10.2
	Peak strength S_p (kPa)	290	520	690
$UU_{Unreinforced}$ at OMC	Modulus E (kPa)	9,600	10,277	11,428
	Strain at failure ε_f (%)	3	8.0	8.8
	Peak strength S_p (kPa)	380	620	900
$UU_{Unreinforced}$ at OMC-2%	Modulus E (kPa)	11,406	11,578	16,666
	Strain at failure ε_f (%)	4.2	7.6	7.8
	Peak strength S_p (kPa)	440	730	1000
$CU_{Reinforced}$ at OMC-2%	Modulus E (kPa)	20,000	43,333	45,000
	Strain at failure ε_f (%)	8.6	2.6	5.2
	Peak strength S_p (kPa)	460	780	1080

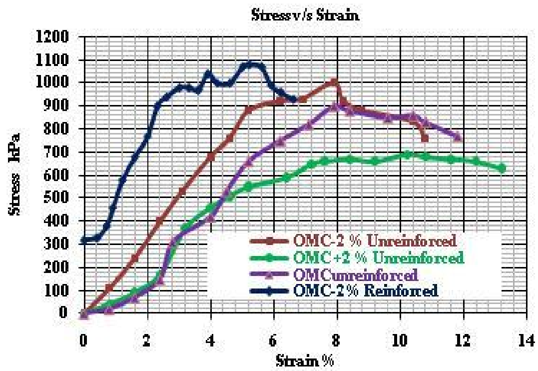

Fig. 5 Stress–strain curves for $UU_{Unreinforced}$ and $CU_{Reinforced}$ for the relative compaction of 95% and the confining pressure 250 kPa

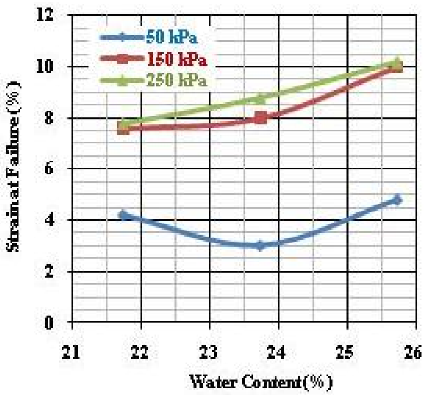

Fig. 6 The variations of strain at failure based on moisture content for 80F + 20C Soil with relative compaction of 95% for $UU_{Unreinforced}$ traixial test

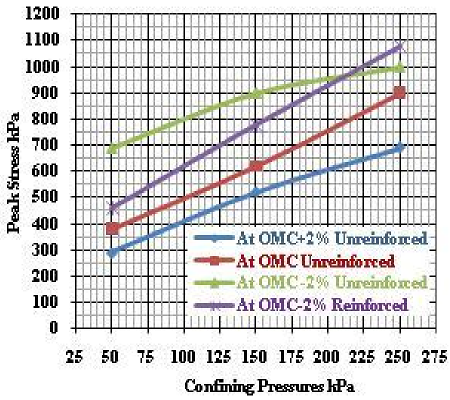

Fig. 7 The variations of peak strength based on confining pressures for 80F + 20C soil with relative compaction of 95% of $UU_{Unreinforced}$ and $CU_{Reinforced}$ traixial test

Table 4 Influence of confining pressure on peak strength ratio (S_R) for 80F + 20C soil type with *PET* woven geotextile at $OMC-2\%$

Confining pressure, σ (kPa)	Peak strength ratio (S_R)
50	1.04
150	1.06
250	1.08

Table 5 Summary of traixial test results

Tests 80% Flyash + 20% Clay	$UU_{Unreinforced}$ Traixial			$CU_{Reinforced}$ Traixial
	$OMC+2\%$	OMC	$OMC-2\%$	$OMC-2\%$
C kPa	57	68	72	80
Φ (°)	30.13	34.02	36.33	37.11
At 250 kPa Cell pressure				
Modulus E (kPa)	10,938	11,428	16,666	45,000
Strain at failure ε_f (%)	10.2	8.8	7.8	5.2
Peak strength S_p (kPa)	690	900	1000	1080

As illustrated in Figs. 6 and 7, it is found that for 80F + 20C soil an increase in the moisture content results in lower peak strength, with an increase in the strain at failure. This was true for higher confining pressure of unreinforced 80F + 20C soil type (Fig. 6).

The influence of confining pressure on the behavior of the reinforced samples is presented in Table 4 for 80F + 20C soils. As the confining pressure increases, the peak strength ratio *(S_R)* also increases which is in conformity with Noorzad and Mirmoradi (2010) observations.

As shown in Fig. 7. For the same confining pressure, the peak strength increases from un-reinforced to reinforced state. An interesting result from this research was that for 80F + 20C soil, the main increase in the peak strength is caused by an increase of cohesion in the reinforced sample with special arrangement of *PET* woven geotextile layers. Also with the 80F + 20C soil, from un-reinforcement to reinforcement state, the cohesion of reinforced samples increases but there is no considerable changes in the internal friction angle, as provided in Table 5. These results are in agreement with the results reported by Srivastava *et al.* (1988) and Noorzad and Mirmoradi (2010).

5. Conclusions

The following conclusions from this study can be made:

1) The stiffness modulus of the reinforced specimen was found to be more than that of the unreinforced specimen. This is contrarily to the study of Haeri *et al.* (2000). This behavior may be justified by the load elongation curve of the geotextile, which is readily provided by the manufacturer.
2) Reinforcing improves the mechanical properties of soil. i.e., inclusion of geotextile increased the peak strength and peak strength ratio of 80F + 20C soil sample. This is caused

by the increase of cohesion intercept in reinforced sample with little or no considerable change in angle of internal friction.

3) Peak strength ratio increases with increase in confining cell pressures and this was true for all confining pressures of reinforced 80F + 20C samples.
4) Reinforced samples are more ductile compared to unreinforced soil samples. At low strains effects of geotextile on peak strength is negligible and only at slight higher strains influence of geotextile layer on soil strength is appreciable.
5) As the moisture content increases, peak strength of the 80F + 20C sample decreases but axial strain at failure increases. The effects of moisture content on these parameters can be directly attributed compaction on flocculent and dispersed structural arrangement of cohesive soils between wet and dry of *OMC*.
6) The fill placement at *OMC* or *OMC + 2%* have higher pore water pressures and hence more settlement compared to reinforced soil at *OMC* – 2% and hence concluded as ideal *OMC* for 80F + 20C composite backfill mix.
7) The geogrids have large openings compared to geotextiles, which have air permeability of 172.26×10^{-4} m^3/s and water permeability of 30 l/m^2/sec. This might help in dissipation or reduction of pore water pressure/ pore air pressure developed as load increases during construction providing better drainage option for 80F + 20C composite backfill mix.
8) Woven geotextile have higher axial strain at failure compared to soils. Therefore for economic design of structures for long term say 100 years; considering geotextile strength at low creep, which will ensure that textile - soil failure strain to be nearly equal shall be beneficial.

Laboratory studies have established that a composition of flyash + clay (80F + 20C) mix as a compatible backfill for geotextile reinforced structures, providing better design parameters and stiffness for stability. Thus this study is an illustration to attempt design of reinforced earth structures from available regional *CH* soil near site of *RE* wall with industrial byproduct flyash to obtain maximum advantage of soil geotextile interaction.

Acknowledgements

Authors wish to express their deepest gratitude and sincere appreciation to Dr. M.D. Desai (Visiting Prof of *AMD*, *SVNIT*, Surat) for his constant guidance, dedication, and encouragement throughout the course of the study. Thanks to Er. H.H. Desai and Er. N.H. Desai (Owner of Unique Advisory Services and Testing, Udhna, Surat) for providing us with the much required lab facilities. Special thanks to Ravin Tailor (Assistant Professor, *CED*, *SVNIT*, Surat) and Babu V.S. (Assistant Manager Design, *REIPL*, Bangalore), for solving our difficulties and support.

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