Engineering Behavior of Soil Stabilized with Byproducts of Plastic Recycling Plant

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ABSTRACT: Reutilization of waste materials in constructional activities is always preferable due to the economical point of view and as an environmentally friendly approach. Hence the use of recycled plastics as an additive in soils during constructional activities is an economic alternative for many soil improvement techniques. The main objective of this study is to improve the engineering properties of the soil samples with the addition of by products from plastic recycling plant. In this study two forms of by products (plastic flakes and pellets) produced during different stages of plastic recycling process is directly used as an additive for soil samples. The engineering properties of the soil samples randomly mixed with the recycled plastic materials are evaluated in the laboratory. Flakes and pellets form of high-density polyethylene plastics are mixed with the soil sample (0 to 2%) and the strength and compressibility properties of each sample are evaluated.

Consolidated undrained triaxial test and one-dimensional compression tests are conducted on each sample and the effect of the plastic addition are studied. From the test results it was observed that the shear strength of the sample increased with the addition of plastic flakes and pellets addition. Compressibility parameters of the sample were reduced with the addition of recycled plastic into the sample. The maximum improvement in the engineering parameters were obtained with the addition of 2% of plastic flakes.

KEYWORDS: Recycled plastic materials, Soil stabilization, Shear strength characteristics, and Compressibility.

1. INTRODUCTION

Sustainable method of construction activities is getting wide acceptance in current scenario because these methods does not cause any adverse effects on environment. The use of different waste materials as the raw materials for different construction activities is always the best alternative for traditional ground improvement techniques. Nowadays different approaches are there, in which the one is using waste soil or material as a replacement for soil during construction. The dredged soils from water bodies and coal mines are some examples of waste material, recently different studies are conducted on these materials for improving its engineering properties and it is used for different applications. Traditional method of chemical stabilization using cement and lime improved the engineering properties of sediments and it was found to be useful for pavement instead of natural soil (Chompoorat *et al.,* 2019, 2021a, 2021b, 2021c, Por *et al.,* 2015). Another approach of sustainable method is using some waste materials for improving the weak natural soil so that it can be used for construction (Reinforcement with waste materials, waste chemical byproducts from different industries etc.). The fly ash material is one of waste product which widely used chemical for improving the engineering properties of weak soils (Chompoorat *et al.,* 2021d, 2022)

The use of byproducts directly obtained from recycling plants as construction materials is the best method in economic point of view and reduce demand of landfilling areas. Plastic materials have applications in various field, but their non-biodegradable nature make it difficult to dispose. The high-density polyethylene plastics are commonly used for manufacture of bottles, toys, food packets etc. and these are sent to recycling plants after use. A standardized procedure is usually adopted in most of the recycling plants, where it is converted into flakes in the initial stage and then converted into pellets. These pellets are then used for manufacture of poor-quality plastic products. Since the first quality plastics are cheaper, the second quality material obtained from recycling plants has no market value, major portion of it is being wasted or sent into landfilling sites. Hence the use of these byproducts as an additive for improving soil properties during construction will reduce the demand of natural soil and at the same time will be an effective method for reducing environmental pollution due to recycled plastics. The waste plastic materials are now used for different applications. Improving the engineering properties of the soil is one of its applications (Peddaiah *et al.,* 2018, Naeini and Rahmani, 2017, Ojuri and Ozegbe, 2016). Similar to these many researchers have conducted studies on uses of recycled plastic materials in the concrete for improving its properties. Recent studies conducted by Adamu *et al.* (2021) and Adamu *et al.* (2022) have evaluated the performance of fly ash concrete mixed with waste plastic materials. Similarly in a study conducted by Jirawattanasomkul *et al.* (2021) they have used recycled plastic straws for providing confinement to the concrete.

In the past few years researchers have conducted studies on soil mixed with recycled plastic fibers and results shown that the random distribution of fibers into the soil improved its engineering behavior. The strength characteristics of the soil mixed with recycled plastic fibers are evaluated by many researchers and many of these studies mainly focused on the effect of fiber length and width on the improvement ratio. In studies conducted on sandy soil mixed with plastic fibers of different length, researchers have concluded that the aspect ratio of the fiber material is having significant role in the strength improvement (Benson and Khire, 1984 and Consoli *et al.,* 2002). Dutta and Venkatappa Rao (2004) conducted triaxial tests on sandy soil mixed with plastic strips made of different plastic materials (High density polyethylene plastic and low-density polyethylene plastic). The significant improvement in the strength parameters is obtained with up to 2 % addition of plastic strip addition. In addition to that they have obtained more improvement factor for high density polyethylene plastic strip mixed soil at high confining pressure and higher stiffness of the high-density polyethylene plastic is found to be the reason for this behaviour. Choudhary *et al.* (2014) conducted studies on sandy soil reinforced with HDPE plastic strips to evaluate the CBR parameters of the sample. They have concluded that with the addition of 4% of strips (width 12mm and l/d ratio varying from 1 to 3) have improved the CBR value to three times as that of unreinforced sample. Chebet and Kalumba (2014) have conducted experiments of soil mixed with polyethylene bag strips with a dimension of 45mmx8mm and they have concluded that significant improvement was observed in the frictional parameters of soil sample. Similar to this Ibrahim *et al.* (2014) studied the hydraulic parameters of the soil sample mixed with fibers made from waste polyethylene bags. They have observed that with the fiber addition the permeability value of the soil sample was reduced up to a certain percentage addition. They have also observed improvement in the strength parameters of the soil sample with fiber reinforcement and found an optimum percentage of 0.3%. Ojuri and Ozegbe (2016) conducted studies on soil mixed with polyethylene plastic strip and cement and found significant improvement in the unconfined compressive strength value of the soil sample. Naeini and Rahmani (2017) studied the influence of the length of the plastic strips on the improvement of the soil -plastic composite. They have stated that as the length of strip increases the improvement ratio increased but only up to certain limit. In addition to that the in the deviator stress value and corresponding strain value was improved with the inclusion of the plastic chips. From the test results they have shown that the effective stress of the reinforced sample is more due to the increase in negative pore pressure value, resulted in increase in the stiffness of the reinforced sample. Peddaiah *et al.* (2018) also conducted similar tests on the soil mixed with polyethylene strips of three different size range (15mm width and three l/d ratio of 1 to 3) but they have observed that significant improvement was observed only for strips of 15mm length.

But in the recycling plants, plastics are obtained in the form of plastic flakes and pellets, hence converting these again into fiber like form will be energy consuming and will make it less economic. In this study the engineering behavior of the soil sample mixed with byproducts of plastic recycling plant is studied.

2. MATERIALS

Byproducts from the plastic recycling plants are used in this study for stabilizing the soil sample and the engineering behavior of the samples are evaluated in the laboratory. Byproducts from the High-density polyethylene plastic recycling plant are plastic pellets and flakes, it was collected from the recycling plant in Kozhikode, Kerala, India. The properties of these two forms of byproducts are shown in Table 1. Figure 1 shows images of recycling plant by products.

Table 1 Physical properties of recycled plant byproducts

	First stage byproduct (Plastic flakes)	Second stage byproduct (Plastic pellets)
Specific gravity of plastic	0.94	0.94
Water Absorption	Nil	Nil
Particle shape	Flat-(thickness 0.2mm)	Bulky
Maximum dimension of particle	15mm	5mm

Figure 1 Plastic flakes and Plastic pellets

Fine grained soil sample is selected as a model soil sample in this study, since the strength and compressibility characteristics of the soil is very poor and need to be improved during the construction activities on the sample. Sandy soils are usually having higher strength properties but the presence of fine contents in the soil will change its behaviour and reduce its strength and compressibility characteristics. Here one fine grained sample was collected from Wayanad, Kerala, India which mainly constitute sand particles and remaining non-plastic fines (Sample A). The presence of plastic fines in the sandy soil is also cause severe changes in the strength and compressibility values of the sample. Hence here one more soil considered for the study which consist of sandy soil mixed with low plastic fines of kaolinite (Sample B). This soil was a laboratory mixed soil in which sand is mixed with kaolinite clay in the proportion of (80:20).

The index properties of these two soil samples are given in Table 2. Grain size distribution of the samples are shown in Figure 2.

Table 2 Properties of soil sample

	Sample A (Field soil)	Sample B (Sand + kaolinite)
Specific Gravity	2.48	2.67
Particle size distribution		
Sand	76%	80%
Silt	22%	6%
Clay	2%	14%
Effective particle size (d10)	0.02mm	0.001mm
Average particle size (d50)	0.25mm	0.4mm
IS Classification	SM	SM
Compaction Characteristics		
Maximum dry density	1.74 g/cc	1.72 g/cc
Optimum moisture content	16%	12%

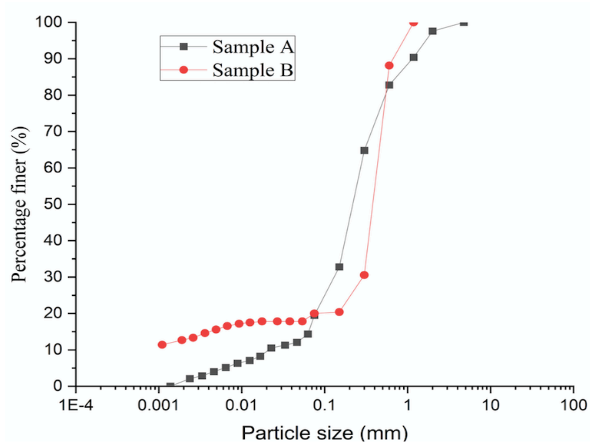

Figure 2 Grain size distribution of soil sample

3. EXPERIMENTAL METHODS

In this section detailed results of various laboratory experiments conducted on different soil samples mixed with plastic recycling plant byproducts are presented.

Three parameters are mainly evaluated in this study, Compaction characteristic, compressibility characteristics and shear strength characteristics. For each soil samples, the plastic byproducts are added in four percentages varying from 0.5% to 2%. Experimental programs of this study are described in Table 3. Each test was repeated thrice to evaluate the repeatability of the test results.

Table 3 Experimental program of the study

Tested sample	Standard compaction test	One dimensional consolidation test	Consolidated undrained triaxial test
• Sample A • Sample A + plastic flakes (0.5% to 2%) • Sample A + plastic pellets (0.5% to 2%) • Sample B • Sample B + plastic flakes (0.5% to 2%) • Sample B + plastic pellets (0.5% to 2%)	18 tests	18 tests (Remarks: Sample prepared with maximum dry density and optimum moisture content)	18 samples X 3 tests (Tested with three confining pressure) (Remarks: Sample prepared with maximum dry density and optimum moisture content)

3.1 Compaction Characteristics

Compaction parameters of the soil sample is evaluated by conducting standard compaction test as per IS 2720-Part VII. The compaction curves for sample A and Sample B mixed with various percentage of plastic recycling plant byproducts (Plastic flakes and pellets) are shown in Figure 3 to Figure 6. From these figures it is observed that addition of plastic flakes and pellets are having a small negative effect on the maximum dry density values of the samples and the variation in the optimum moisture content of the sample was found to be less significant. The density of the plastic pellets and flakes are smaller than the soil particles and hence this will be probable reason for reduction in the maximum dry density values of the soil-plastic composite.

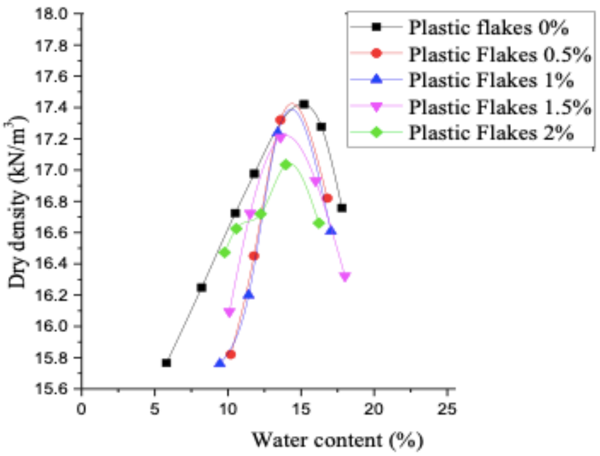

Figure 3 Compaction curves of sample A mixed with flakes

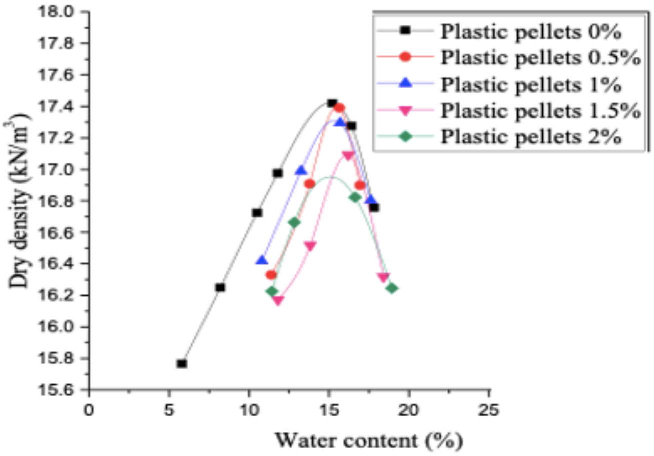

Figure 4 Compaction curves of sample A mixed with pellets

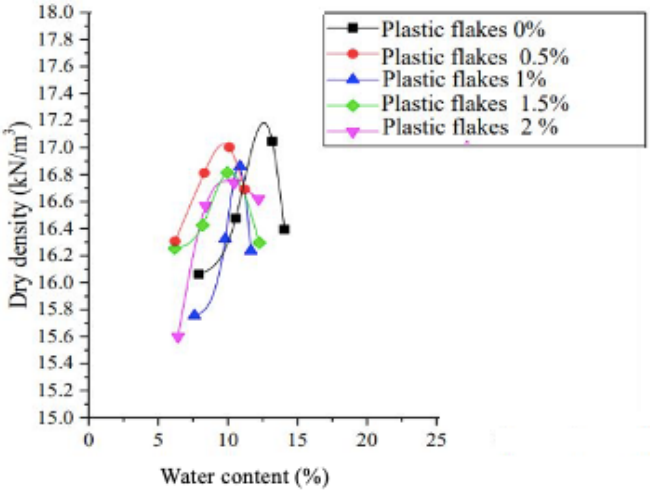

Figure 5 Compaction curves of sample B mixed with flakes

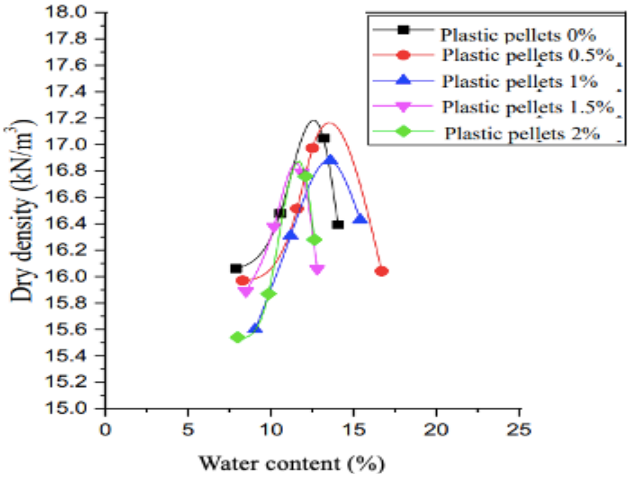

Figure 6 Compaction curves of sample B mixed with Pellets

In addition to that the water absorbing capacity of the plastic materials are nil and hence it has less significant effect on the optimum moisture content values of the soil sample. The maximum variation in the optimum moisture content of sample were within 2% with the addition of plastic materials. Similar results were obtained in previous studies conducted on cohesionless soil samples mixed plastic fibers and strips (Arulrajah *et al.*, 2017, Ojuri and Ozegbe 2016, and Laksar and Pal, 2013). However, in a study conducted by Peddaih *et al.* (2018) on cohesive soil mixed with plastic fibers they have obtained small percentage of increase in the maximum dry density values.

3.2 Compressibility Characteristics

Compressibility characteristics of the soil sample is evaluated by conducting one dimensional consolidation test on soil samples mixed with plastic recycling plant by-products (Plastic pellets and plastic flakes). In the consolidation test samples were prepared with maximum dry density and optimum water content of each sample obtained from compaction test. The samples were prepared by mixing the recycled materials in different percentages varying from 0.5 to 2% of dry weight of soil sample and mixing is done carefully so that the plastic materials are uniformly distributed throughout the soil sample. Eighteen consolidation tests were conducted and teste were repeated systematically and test results were evaluated. Each tests were repeated three times to evaluate the repeatability of the results. Initial load of 5 kPa was applied to the sample as a seating load and then the load was increased incrementally up to 800 kPa and the variation in the void ratio for each load increment was noted. After completing the loading, the sample was unloaded and void ratio changes was noted. From the results, the variation between the void ratio and stress values are plotted with stress values in logarithmic scale. The graphs are shown in Figure 7 to Figure 10. The initial void ratios of the soil samples was reduced with the addition of the plastic content in to the soil, which is due to the lower specific gravity values of the High density polyethylene plastic material (0.94). From the e – log P graphs the compressibility index and recompression index values of the soil samples are calculated.

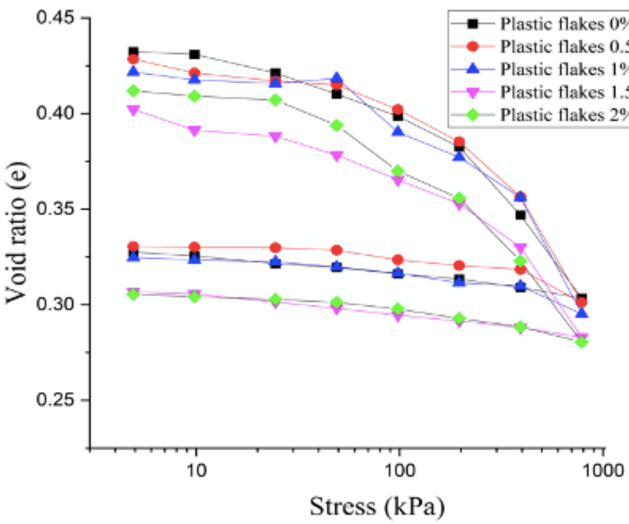

Figure 7 e-log P curve of Sample A mixed with flakes

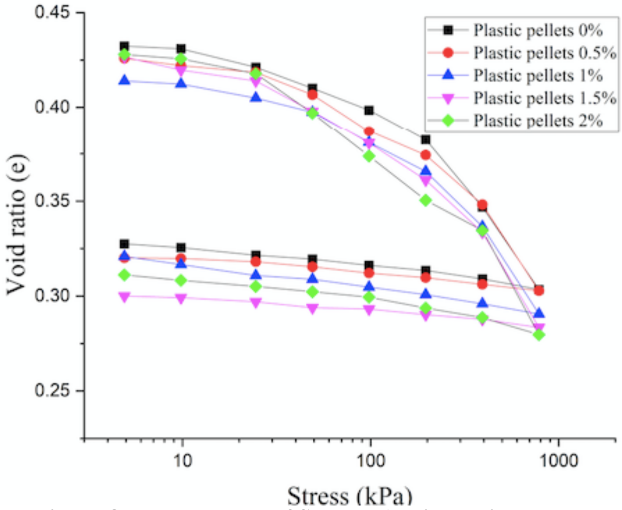

Figure 8 e-log P curve of Sample A mixed with pellets

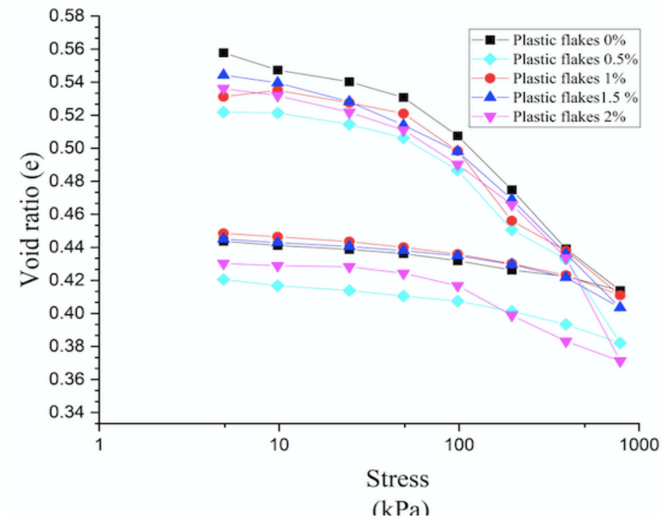

Figure 9 e-log P curve of Sample B mixed with flakes

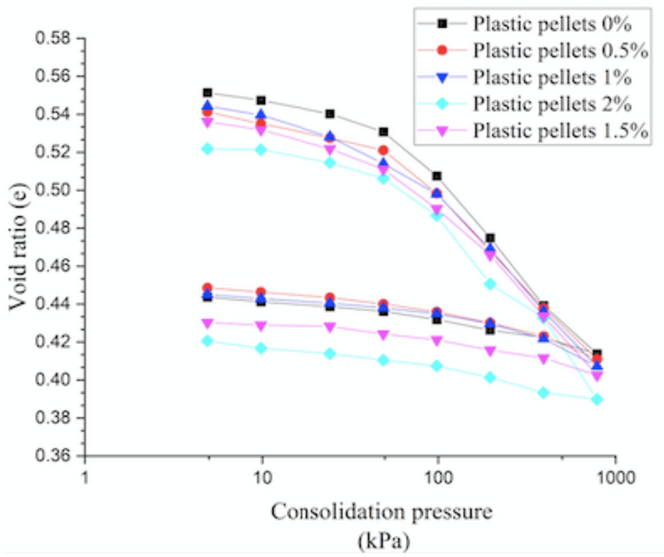

Figure 10 e-log P curve of Sample B mixed with pellets

Table 4 Compressibility Characteristics

	Percentage of additive (%)	**Compression index Value (C_C)**	**Re-compression index value (C_r)**	**Modulus of volume Compressibility (m_V)(m^2/kN)**
Sample A (Field soil)	0%	0.081	0.014	$1x10^{-4}$
Sample A with Plastic pellets	0.5%	0.065	0.014	$1x10^{-4}$
	1%	0.058	0.013	$2x10^{-4}$
	1.5%	0.056	0.009	$2x10^{-4}$
	2%	0.053	0.011	$2x10^{-4}$
Sample A with Plastic flakes	0.5%	0.062	0.010	$1x10^{-4}$
	1%	0.053	0.010	$9x 10^{-5}$
	1.5%	0.048	0.010	$1x10^{-4}$
	2%	0.057	0.011	$1x10^{-4}$
Sample B (Sand +Kaolinite)	0%	0.115	0.01	$8x10^{-5}$
Sample B with Plastic pellets	0.5%	0.103	0.008	$8x10^{-5}$
	1%	0.102	0.008	$8x10^{-5}$
	1.5%	0.095	0.006	$9x10^{-5}$
	2%	0.089	0.003	$9x10^{-5}$
Sample B with Plastic flakes	0.5%	0.108	0.009	$8x10^{-5}$
	1%	0.101	0.007	$9x 10^{-5}$
	1.5%	0.085	0.002	$1x10^{-4}$
	2%	0.086	0.002	$1x10^{-4}$

The values of the of different parameters like compression and recompression index, modulus of volume compressibility and modulus of volume re- compressibility of soil samples mixed with plastic components are presented in Table 4. From the results it is observed that, with the increase in the plastic content the gradual reduction in the compressibility index values were observed for both type of soil samples with the addition of plastic flakes and pellets. From the results it was observed that for a particular stress increase, reduction in the equilibrium void ratio of the samples decreased. Similar observations are obtained for Soltani Jigheh (2016) and Babu and Chouksey (2011) on soil sample reinforced with plastic chips. Maximum reduction in the compression index values of the sample A was 40.47 % which is obtained for sample A mixed with plastic flakes 1.5%. The effect of the plastic content on the compression index of the sample B was lesser than that of the sample A. This may be due to the more clay content in the soil sample. In this study maximum reduction in the compression index value for sample B was obtained as 22.26% which was observed for the sample B mixed with 2 % of the plastic pellets. The effect of the type of the recycled plastic materials on the compressibility behavior of the soil sample was less significant.

3.3 Strength Characteristics

The shear strength parameters of the soil mixed with plastic recycling plant byproducts (Plastic flakes and pellets) are evaluated by conducting consolidated undrained triaxial test. The soil samples were mixed with different percentages of plastic flakes and plastic pellets and the test were conducted on different confining pressures. The initial conditions of the soil sample like soil type, plastic content, density, water content etc. influence the shear strength parameters of the sample. Here for testing the soil sample was prepared with the maximum dry density and optimum water content. Many researchers are also conducted studies on soil sample at these initial conditions for all soil sample (Babu and Chouskey, 2011, Sivakumar babu and Raja jaladurgam, 2014). Sample of required density was prepared by using dry funnel deposition method. Initially untreated soil sample was tested and then the soil was mixed with recycled plant by-products materials in different percentages varying from (0.5%-2%). All the samples were prepared in a mould of diameter 50mm and length to diameter ratio of 2. Eighteen sets of samples were prepared with soil mixed with varying percentages of plastics and these samples were tested in three confining pressures. To evaluate the repeatability of the test results, the tests were repeated three times and the observations are noted. To achieve uniform mixing 10% water was added to the soil while preparing the soil-plastic composite for testing recycled plastic flakes. Similar method was adopted in different studies conducted on randomly reinforced soil samples. (Muntohar *et al.,* 2013, Soltani Jigheh, 2016, Consoli *et al.,* 2002).

Shear strength parameters of the soil samples mixed with plastic recycling plant products are tabulated in Table 5. The peak deviator stress values of the samples in three different confining pressures are also tabulated (50, 100 and 150 kPa). For the soil sample A, the peak deviator stress value of the sample was 189kPa at 150kPa confining pressure and it was increased to 294 kPa with the addition of 2% of plastic flakes. But increasing rate of the deviator stress value was less significant beyond 1.5% addition of plastic flakes. This may be due to the non-uniform mixing of the plastic flakes. In studies conducted by researchers on plastic fiber mixed soil sample they have observed similar results and they have concluded that higher percentage of plastic content may cause negative results due to non–uniform mixing (Soltani Jigheh, 2016 and Rawat and Kumar, 2014). In these studies, they have limited the percentage of plastic strips as 1.5%. The variation of deviator stress values with axial strain of the soil sample A mixed with varying percentages of recycled plastic products are shown in Figure 11 and Figure 12. From the graphs it can be observed that with addition of the plastic flakes into the soil sample the failure strain of the sample was increased. This may be due to the higher tensile resistance offered by the plastic flakes. Similar results were obtained in a study conducted by Sivakumar babu and Raja Jaladurgam (2014) in soil mixed with plastic strips. With increase in the confining pressure values the peak deviator stress values of the soil samples were increased. Maximum improvement of 55% was obtained for soil sample A mixed with 2% of plastic flakes tested in 150kPa confining pressure. However this much improvement was not obtained for the soil sample mixed with plastic pellets. From the results only small percentage of increase was observed in the peak deviator stress values of the sample mixed with varying percentages of plastic pellets. Shape of these pellets cannot make significant changes in the frictional parameters of the sample, since its slenderness ratio is less compared to that of flakes, and this material can't impart more tensile resistance to the soil sample. However, as we are focusing on usage of a recycling material economic benefit is more important, hence the use of recycled material directly from the recycling plant without further conversion makes this method more economical. The frictional angle and the cohesion parameter of the samples are tabulated in Table 5, from these results it is observed that the with the addition of the plastic flakes into the soil sample cohesion value of the sample A was increased from 5kPa to 23kPa with the addition of 2% of plastic flakes into the soil sample. This may be due to the apparent cohesion developed inside the soil sample due to addition of flakes into the soil. In a study conducted by Sivakumar Babu and Raja Jaladurgam (2014) they have observed development of apparent cohesion in the soil-plastic strip mix and hence increased the shear strength value of the sample. Here improvement in the shear strength of the soil sample is mainly due to the apparent cohesion developed inside the sample, small percentage improvement was observed in the frictional angle of the sample. This may be due to the surface characteristics of the plastic flakes. Improvement in the soil sample mixed with the second stage by-product (Plastic pellets) is less significant compared with that of soil mixed with plastic flakes. The smooth surface and less slenderness ratio of the plastic pellets is the reason for smaller improvement ratio than the plastic flakes. However small percentage of improvement in the shear strength parameters is observed even with the addition of plastic pellets into the soil, considering the economic benefit of using these recycled plastic pellets, we can use these as additive for soils during construction.

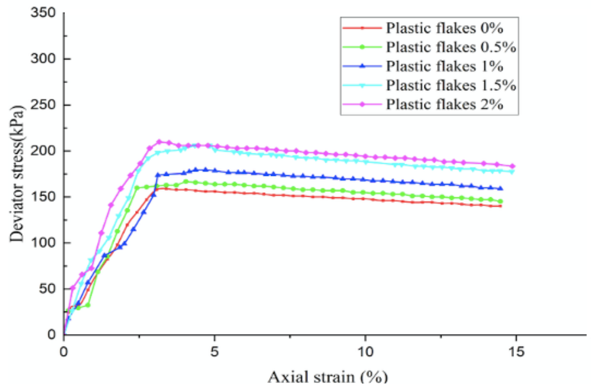

Figure 11 Deviator stress vs Axial strain (Sample A + Flakes 100kPaa)

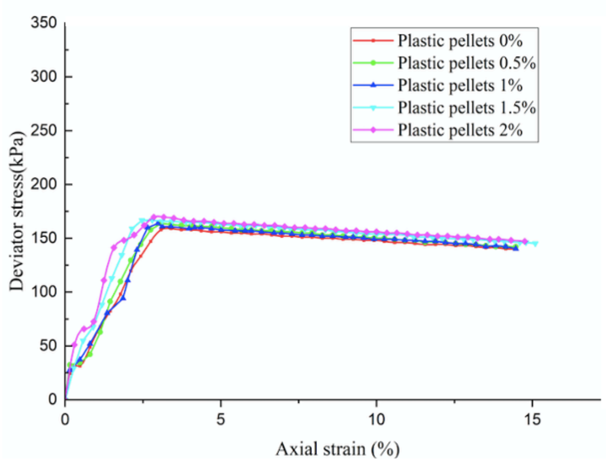

Figure 12 Deviator stress vs Axial strain (Sample A +Pellets 100kPa)

Consolidated undrained triaxial tests were also conducted in Sample B, which is a mixture of sand kaolinite clay. Triaxial tests were conducted on the soil samples mixed with varying percentages of plastic flakes and plastic pellets, and on three different confining pressure also. The results are tabulated in Table 5. The variation in the deviator stress of the samples with axial strain is shown Figure 13 and Figure 14. Similar to results obtained from Sample A, here also more improvement in peak deviator stress values was obtained for the sample B mixed with plastic flakes. With increase in the plastic flakes content the peak deviator stress value of the sample was also increased. Maximum improvement in the deviator stress was 30% with the addition of 2% plastic flakes with a confining pressure of 150kPa. The percentage increase of peak deviator stress of sample B was less compared to sample A. This may be due to the presence of weak clay component in the soil sample B. Similar to the results obtained for the sample A mixed with plastic pellets, here also comparatively less improvement was observed. The shear strength values of the sample B mixed with plastic recycled products shows that the plastic flakes can induce an apparent cohesion to sample and can increase the shear strength values of the sample. The cohesion value of the soil sample was increased from 10kPa to 22kPa with the addition of 2% of plastic flakes into the sample. But only small percentage of increase was observed in the frictional angle of the sample, which is due to the surface characteristics of recycled product. Because of the slenderness ratio, more improvement in the shear strength parameters was obtained with the addition of plastic flakes into the sample.

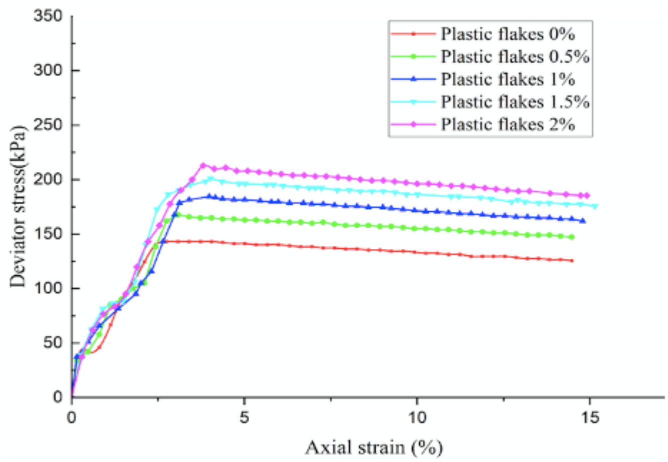

Figure 13 Deviator stress vs Axial strain (Sample B +Flakes 100kPa)

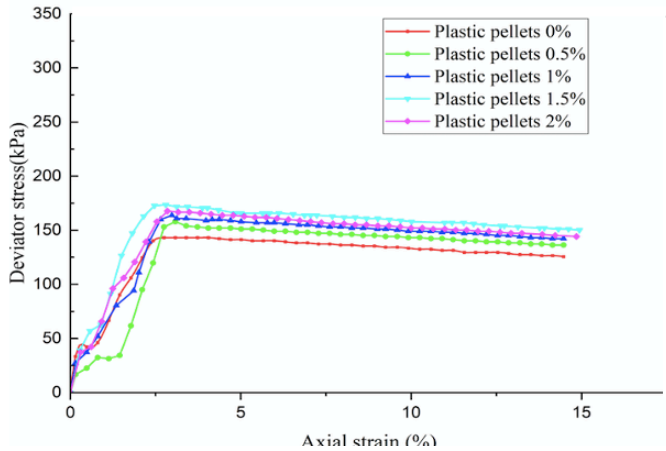

Figure 14 Deviator stress vs Axial Strain (Sample B + pellets 100kpa)

Table 5 Shear strength characteristics

	Peak deviator stress (At different confining pressures)			Cohesion (kPa)	Friction angle (degrees)	Shear strength (kPa)
	50 kPa	100 kPa	150 kPa			
Sample A (Field Soil)	89	159	189	5	25.5	52.67
Sample A mixed with						
0.5% flakes	93	167	211	10	26.1	58.96
1% flakes	101	180	256	14	27.2	65.36
1.5% flakes	121	206	282	21	28.0	74.14
2% flakes	126	209	294	23	28.4	77.04
0.5% pellets	96	164	189	7	25.6	54.88
1% pellets	102	164	194	8	24.8	54.18
1.5% pellets	98	166	188	10	25.8	58.31
2% pellets	93	169	190	11	24.7	57.18
Sample B (Sand +Kaolinite)	92	143	201	10	21.8	49.97
Sample B Mixed with						
0.5% flakes	110	168	211	14	22.1	54.38
1% flakes	128	184	230	15	22.9	57.22
1.5% flakes	143	201	244	20	24.2	64.92
2% flakes	157	212	262	22	24.8	68.18
0.5% pellets	97	158	207	11	20.6	48.61
1% pellets	103	163	212	14	22.1	54.58
1.5% pellets	110	174	220	18	23.1	60.63
2% pellets	106	168	222	16	22.8	58.01

4. CONCLUSIONS

Engineering behavior of two types of soil samples mixed with two byproducts from a plastic recycling plant (Plastic flakes and Plastic pellets) was studied through various geotechnical laboratory tests. Compressibility and shear strength characteristics of the samples mixed with varying percentages of plastic flakes and pellets were evaluated.

From consolidation test results it was observed that the compressibility of the soil sample decreased with increase in the plastic product content. Reduction in the compression index of samples were obtained with the addition of incompressible plastic materials. However, the type of recycling material does not make significant changes in the reduction percentage of compressibility index. The addition of the plastic flakes (1.5%) material into the silty sandy soil (sample A) caused maximum reduction in the compression index.

From consolidate undrained test results it was observed that peak deviator stress values of the soil samples increased with the addition of plastic flakes. In addition to that apparent cohesion was induced in both types of soil samples with the addition of plastic flakes, leading to an increase in the shear strength values. However, the plastic pellets have less significant changes in the shear strength parameters of the sample. The maximum improvement in the shear strength of the sample A (46% improvement) was obtained with the addition of 2% plastic flakes into the sample. Sample B also showed improved shear strength (36% improvement) with the addition of 2% of plastic flakes.

From these test results it can be concluded that the by products from plastic recycling plants can effectively be used as an additive for less cohesive soil samples. Further studies must be conducted to evaluate its effectiveness on cohesive soil samples. The use of the by products directly from recycling plants without further conversion will make this method more economical. At the same time this will reduce demand of landfill area required for disposal of plastic waste.

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