Utilization of Waste Plastic Shreds for Stabilization of Soil

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Abstract When soil available for construction is not suitable for the intended purpose, then soil stabilization is required. In this study, two soil samples were collected from Margoa, Goa State and were reinforced with waste plastic shreds. These plastic shreds were obtained from plastic packaging waste which would cause a major disposal problem for the environment. Waste plastic shreds were added in varying percentages like 2, 4, 6, 8, and 10% to the soil samples as a reinforcement material. From compaction test, maximum dry density (MDD) and optimum moisture content (OMC) were determined and shear strength parameters (cohesion and friction) were obtained from box or direct shear test. For the first soil sample, there was a decrease in MDD, OMC, and cohesion and a slight increase in friction with an increase in the percentage of reinforcement. For the second sample also, almost the same results were obtained that means decrease in MDD, OMC, and cohesion and a slight increase in friction with increase in the percentage of reinforcement. The decrease in maximum dry density of soil must be due to low specific gravity of plastic shreds. Also it has been observed that adding beyond 10% of plastic waste would not vary much in MDD value. The present work concluded that the stabilized soil could be utilized for roadways, parking areas, site development projects, airports, and many other situations where subsoils are not suitable for construction.

Keywords Soil · Stabilization · Plastic waste

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1 Introduction

If the engineering properties of soil are undesirable and not suitable for construction purposes, then soil stabilization is required. Soil stabilization process improves the shear strength parameters and controls the shrink–swell properties of a soil. So it helps to enhance the physical properties and load-bearing capacity of a soil. It is mainly used to increase bearing capacity of a subgrade soil to support pavements and foundations. In earth structures, it is used to reduce permeability and compressibility of the soil mass. So overall it is the process of alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil. In this process, a special soil, cementing material, or other chemical materials are added to a natural soil to improve its properties. It can be achieved by mechanically mixing the natural soil and stabilizing material together so as to achieve a homogeneous mixture. Otherwise by adding stabilizing material to an undisturbed soil deposit and obtaining interaction by letting it permeate through soil voids (Perloff 1976). Reinforced soil is the one in which soil fill is strengthened by a variety of tensile inclusions. These tensile inclusions are in many forms ranging from strips and grids to discrete fibers and woven and nonwoven fabrics.

Nowadays the volume of plastic material in municipal solid waste generated across the world has grown because of the widespread increase of single-use plastics in day-to-day consumer applications. More than 50% of the discarded plastics come from packaging applications. So, waste plastic becomes the main problem in many areas, especially in landfills. These waste plastics are not a biodegradable material, hence, may cause serious environmental pollution also, Siddiqui (2009). In the past few decades, the rate of production of plastic waste has been increased tremendously in almost all parts of the world due to population growth, industrialization, and technological development. The conventional waste disposal methods are found to be inadequate. In this regard, a small attempt has been made in this research work to use waste plastic as a reinforcing material to improve the strength of soil.

The usage of plastic waste for soil stabilization was studied in research programs from around the world. Khedari et al. (2005) developed a new type of soil–cement block using coconut coir with low thermal conductivity. They considered various mixture ratios and fabricated five specimens per sample using local handmade manufacturing process. In their study, thermal conductivity, compressive strength, weight, and bulk density of specimens were investigated, and they concluded that the use of coconut fiber as an admixture can reduce the block thermal conductivity and weight. Babu and Vasudevan (2008) studied strength and stiffness response of coir fiber-reinforced tropical soil. They reported that the strength and stiffness of tropical soil were increased with the inclusion of about 1–2% discrete coir fibers by weight. Subaida et al. (2009) carried out research on laboratory performance of unpaved roads reinforced with woven coir geotextiles. Their test results indicated that the inclusion of coir geotextiles enhanced bearing capacity of thin sections.

Placement of geotextile at the interface of the subgrade and base course increased load-carrying capacity significantly at large deformations. Also they found that considerable improvement in bearing capacity when coir geotextile was placed within the base course at all levels of deformations. The plastic surface deformation under repeated loading was greatly reduced by the inclusion of coir geotextiles within the base course irrespective of base course thickness. Muntohar (2009) investigated the strength of stabilized clay soil reinforced with randomly distributed discrete plastic waste fibers by carrying out unconfined compressive strength and tensile-split strength test. In their study, the clay soil was stabilized with lime and rice husk ash mixtures. The effect of the fiber length and content on the compressive and split tensile strength was investigated. Their laboratory investigation results showed that inclusion of the plastic waste fiber increased unconfined strength and tensile-split strength of the stabilized clay soil significantly. Dasaka and Sumesh (2011) reported that varying the length of coir fibers and content in soil results in an improvement in the strength characteristics. Hejazi et al. (2012) reviewed the use of natural and synthetic fibers as construction and building materials and reported that fiber reinforcement improves the strength and stiffness of composite soil. Azzam (2013) studied behavior of modified clay microstructure using polymer nanocomposites technique. They illustrated the application of using polymer stabilization in creating a new nanocomposite material with clay soil. Their experimental results showed that the resulting nanocomposites acted as nanofiller materials which decreased the plasticity and compressibility parameters of the treated clay. Gupta and Sharma (2016) studied black cotton soil modification by the application of waste materials. They presented an approach of improvement in the various geotechnical properties of black cotton soil, by blending it with waste materials such as river sand, fly ash, and marble dust. They observed that the impact effect of waste materials on the environment was reduced mainly due to optimum utilization of these waste materials in the improvement of various properties of black cotton soil. Prasanna and Kumar (2017) carried out a research on soil reinforcement using coconut shell ash as waste material for Indian soil. By comparing all the results, they observed that Atterberg's limits such as maximum liquid limit was achieved at 2% and maximum plastic limit was at 10% coconut shell ash reinforcement. Then regarding compaction, they concluded that by adding at 0.8% of waste achieved maximum improvement of MDD and OMC. From direct shear test results, they concluded that angle of internal friction and cohesion was achieved at the range of 0.4–0.8%.

A very few literatures are available on stabilization of sandy soils with shredded plastic wastes for the coastal region of Goa, India. This article is the one which provides various properties of soil and explains how the properties of soil can be stabilized using shredded plastic wastes for the region under consideration. The main objectives of this study are to: To carry out physical test on soil without reinforcement, to carry out physical test on soil with reinforcement (shredded plastic waste) in varying percentages, to analyze the specimen for shear strength and compaction, to compare results of the test conducted on ordinary soil and soil with reinforcement.

2 Materials and Methodology

The soil samples used in this study were obtained as undistributed samples along the coastal region of Goa. The study area falls under the district of South Goa in the Taluka of Salcete in India. The samples were taken from Fatorda village falling in the above said region. The samples were of sandy-textured soil. The shredded plastic wastes (Fig. 1) were collected from plastic packaging industry. In this project work, experimental study was conducted with shredded plastic waste as reinforcing material to increase the strength of soil. Different tests were conducted on soil sample with varying percentage of shredded plastic waste. The samples were subjected to different laboratory tests, such as moisture content, bulk density, specific gravity, particle size distribution, Atterberg limits, compaction, and direct shear test.

3 Results and Discussion

Undisturbed samples were collected from the field and different laboratory tests were conducted. Moisture content and specific gravity of the sample 1 was found to be 13.41 and 2.76%, respectively. Sieve test was performed on sample 1 and identified soil as sandy soil. Then Atterberg's limit (liquid limit and plastic limit) test was performed on sample 1. The values of liquid limit (LL), plastic limit (PL), and plasticity index (PI) obtained were 26.3, 9.69, and 16.51%, respectively. Reinforcement analysis was done only for compaction and direct shear tests with different percentages of shredded plastic wastes. After that, optimum moisture content (OMC) and maximum dry density (MDD) were found by compaction test. The following results were observed for the sample 1. OMC was found to be 19.5% and MDD was 2.05 g/cm^3. After addition of shredded plastic wastes as reinforcement in various percentages, the following changes were obtained. For addition of 2% of shredded plastic wastes, OMC and MDD were decreased to 19.1% and 1.86 g/cm^3. Again after addition of another 2% that is a total of 4% shredded plastic wastes, OMC and MDD were 17.5% and 1.76 g/cm^{3,} respectively. Here also OMC and MDD reduced slightly. For 6% of shredded plastic wastes, OMC and MDD again decreased by 16.82% and 1.72 g/cm^{3,} respectively. At 8%, OMC and MDD was 15.45% and 1.7 g/cm^{3,} respectively. Again OMC and MDD were decreased to 14.3% and 1.54 g/cm^3 with addition of 10% of shredded plastic wastes. From this, it could be observed that with the addition of shredded plastic wastes as reinforcement, optimum moisture content, and maximum dry density were decreased. The results are shown in the following Table 1. Figure 2 shows the results of OMC and MDD with different percentages of shredded plastic waste for sample 1.

For sample 2 also, similar tests were conducted. Moisture content and specific gravity were 15.22 and 2.42%, respectively. From the sieve test, it was found that

Fig. 1 Plastic shredding machine and shredded plastic

soil belongs to sandy soil. Atterberg's limit, i.e., LL was 32.4%, PL was 16.41%, and PI was 15.99. Then compaction test was carried out and found OMC (23.52%) and MDD (1.50 g/cm^3) without adding waste material. For this sample also, similar trend was observed that is with the addition of shredded plastic wastes as reinforcement, optimum moisture content, and maximum dry density were decreased. At 2%, OMC and MDD were 23% and 1.49 g/m^3, at 4% OMC (21.93%) and MDD (1.48 g/m^3), at 6% OMC (21.60%) and MDD (1.47 g/m^3), at 8% OMC (21.40%)

Table 1 Optimum moisture content (OMC) and maximum dry density (MDD) with different percentages of wastes for sample 1 and 2

% of plastic waste (%)	Sample 1	Sample 2
0	OMC = 19.50% MDD = 2.05 g/cc	OMC = 23.52% MDD = 1.500 g/cc
2	OMC = 19.10% MDD = 1.86 g/cc	OMC = 23.00% MDD = 1.50 g/cc
4	OMC = 17.50% MDD = 1.77 g/cc	OMC = 21.93% MDD = 1.48 g/cc
6	OMC = 16.82% MDD = 1.72 g/cc	OMC = 21.60% MDD = 1.47 g/cc
8	OMC = 15.45% MDD = 1.70 g/cc	OMC = 21.40% MDD = 1.43 g/cc
10	OMC = 14.30% MDD = 1.54 g/cc	OMC = 20.40% MDD = 1.39 g/cc

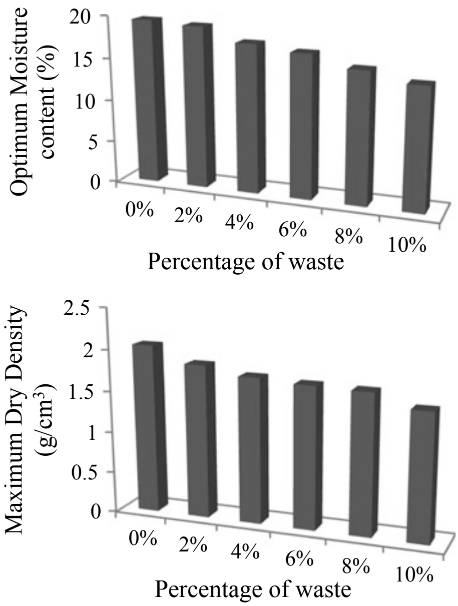
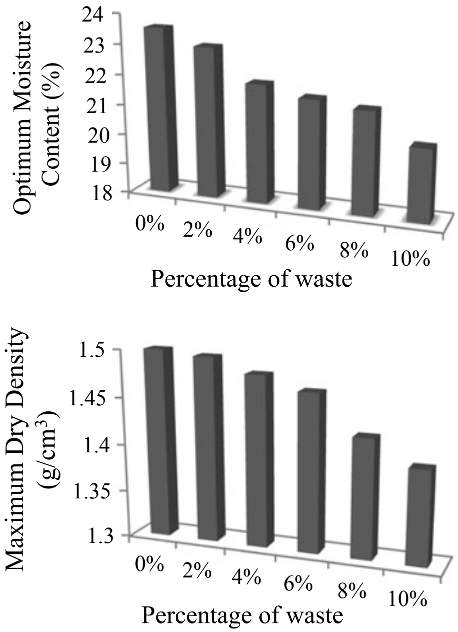


Fig. 2 Optimum moisture content (OMC) and maximum dry density (MDD) with different percentages of wastes for sample 1

and MDD (1.43 g/m^3), and at 10% OMC (20.4%) and MDD (1.40 g/m^3), respectively. This result shows that there was a slight reduction in MDD and OMC values with increase in the percentage of reinforcement. It has been observed that mixing beyond 10% of plastic waste would not vary much in MDD value. The results are shown in Table 1. Figure 3 shows the results of OMC and MDD with different percentages of shredded plastic waste for sample 2.

Fig. 3 Optimum moisture content (OMC) and maximum dry density (MDD) with different percentages of wastes for sample 2



Then shear strength parameters of soil, i.e., cohesion (c) and angle of friction (ϕ) were determined using direct shear test. First for sample 1, unreinforced test was conducted; a shredded plastic waste was not used. The following c = 0.195 kg/cm^2 and ϕ = 8° values were obtained. Generally, higher the friction and cohesion values better are the shear strength of the soil and also the stability of the slope. Then soil was reinforced with shredded plastic waste in different percentages. With 2% of shredded plastic waste as reinforcement, the following c = 0.1 kg/cm^2 and ϕ = 8° values were obtained. In this case, cohesive value decreased exponentially, but the angle of internal friction remained the same. At 4%, c = 0.085 kg/cm^2 and ϕ = 9°. Here cohesion decreased and friction increased slightly. At 6%, c = 0.1 kg/cm^2 and ϕ = 10.5°. Here both cohesion and friction were increased slightly. At 8%, c = 0.095 kg/cm^2 and ϕ = 12° slight increase in friction value. At 10%, angle of internal friction remained constant (ϕ = 12°) and cohesion increased to 0.14 kg/cm^2. Here it could be observed that an angle of internal friction increased exponentially, but the cohesive value is reduced slightly. Further at 4, 6, 8, and 10% cohesion value was varying but not linear in nature. The angle of internal friction was increased as the percentage of reinforcement was increased. Figure 4 shows the comparison of friction and cohesion values with different percentages of shredded plastic waste for sample 1. Table 2 shows the results of direct shear test for sample 1 and 2.

For sample 2 also, direct shear test was conducted and found cohesion and friction values. For unreinforced soil, i.e., without adding shredded plastic waste, the following c = 0.24 kg/cm^2 and ϕ = 11° values were obtained. When reinforced with shredded plastic waste, at 2%, c = 0.15 kg/cm^2 and ϕ = 13°, here cohesion

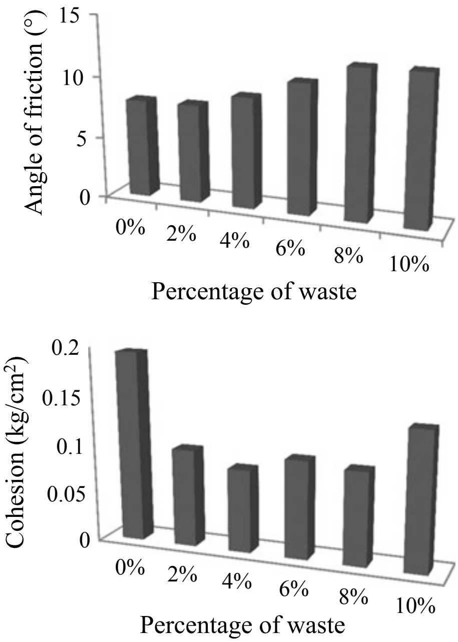


Fig. 4 Angle of internal friction (ϕ) and cohesion (c) with different percentages of waste for sample 1

Table 2 Angle of internal friction (ϕ) and cohesion (c) with different percentages of wastes for sample 1 and 2

% of plastic waste (%)	Sample 1	Sample 2
0	$c = 0.195$ kg/cm^2 $\phi = 8°$	$c = 0.24$ kg/cm^2 $\phi = 11°$
2	$c = 0.10$ kg/cm^2 $\phi = 8°$	$c = 0.15$ kg/cm^2 $\phi = 13°$
4	$c = 0.09$ kg/cm^2 $\phi = 9°$	$c = 0.12$ kg/cm^2 $\phi = 14°$
6	$c = 0.10$ kg/cm^2 $\phi = 10.5°$	$c = 0.13$ kg/cm^2 $\phi = 19°$
8	$c = 0.095$ kg/cm^2 $\phi = 12°$	$c = 0.09$ kg/cm^2 $\phi = 19°$
10	$c = 0.14$ kg/cm^2 $\phi = 12°$	$c = 0.10$ kg/cm^2 $\phi = 22°$

was decreased slightly but friction was increased. At 4%, $c = 0.12$ kg/cm^2 and $\phi = 14°$, again cohesion deceased and friction increased. At 6%, $c = 0.13$ kg/cm^2 and $\phi = 19°$, here cohesion value decreased slightly but friction value increased drastically. At 8%, $c = 0.09$ kg/cm^2 and $\phi = 19°$. At 10%, $c = 0.10$ kg/cm^2 and $\phi = 22°$. For both 8 and 10% cohesion value decreased and friction value increased. So for this sample also the same conclusion was drawn that means the angle of internal friction increases as the percentage of reinforcement increases. The results are shown in Table 2 and Fig. 5.

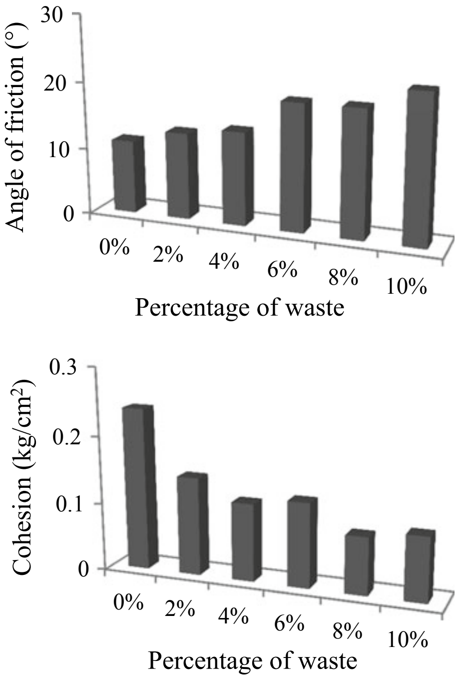


Fig. 5 Angle of internal friction (ϕ) and cohesion (c) with different percentages of waste for sample 2

4 Conclusions

Shredded plastic waste can be considered as an eco-friendly material for soil stabilization. It has lower carbon content than cement or other hydraulic binders. In this study, considerable results were obtained by mixing soil with various percentages of waste shredded plastic. An addition of shredded plastic waste decreased the maximum dry density and optimum moisture content of the soil. The angle of internal friction (ϕ) increased and cohesion (c) decreased considerably with inclusion of different percentages of shredded plastic waste in both soil samples. This study suggests that if shredded plastic is properly mixed and applied, then it could be used as an economical soil stabilization material. And also it eradicates the disposal problem of plastic waste. Further research in this field may shed light on the application of plastic material for stabilization of soil. Finally, this study concluded that shredded plastic waste could be used as one of the waste materials for soil reinforcement in the region under consideration.

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