Section A-Research paper
ISSN 2063-5346

Evaluation of Plastic Waste Reinforced Soils for Sustainable Road Construction

Arpit Vyas[1, 2] [0009-0005-1605-0728] and Dr. Anil Ghadge[1] [0000-0003-2458-8358]

[1] Sardar Patel College of Engineering, Mumbai 400058, India
[2] Thakur College of Engineering and Technology, Mumbai 400101, India
arpitvyas73@gmail.com

Abstract. Plastic waste (PW) is identified as the biggest health hazard to human life in recent years. Efforts to ban use of plastic by various sanctions have been futile due to their economic advantage, usefulness, durability, and versatile nature. To address the challenges posed by indiscriminate dumping of plastic waste various efforts to recycle it have been initiated but they have remained insufficient due to the high cost of collection, cleaning, and sorting before they can be recycled. And therefore, it is important to upcycle the plastic waste into secondary purposes where their strength and durability can be used to the advantage of the society. Most road failures in India start with failure of subgrade soil, compacted soil subgrade occupies about 50-70% volume of a flexible pavement. their strength and swell behavior is affected by water penetration. studies have incorporated various reinforcing materials to enhance strength of weak soils. This investigation explores the effects of plastic waste as a soil reinforcing material for improving weak properties of soils by evaluating water adsorption, swelling behavior and strength of soil. Locally available marine clay and fine gravel were reinforced with plastic waste, the results demonstrate an increase of 11% and 18% in California bearing ratio (CBR), reduction in swell behavior and increase in shear strength. This enhancement of strength can be a boon in construction of roads as this may prevent failure of pavement, increase durability of roads and support the PW handling small business to ultimately provide a sustainable approach to plastic waste management.

Keywords: Plastic waste, Sustainable road, Durable road, Reinforced subgrade, CBR value

1 Introduction

Various types of plastics perform essential functions in our everyday life due to its lightweight, versatility, low cost of production, durability and thermal insulation in comparison with its competing materials. These properties have made plastics to become essential in every aspect of life[1] But once discarded, they become a huge menace to the society, it is observed that just 9% of all plastic manufactured gets recycled, 12% is burnt, and 79% is accumulated in landfills or natural water bodies and soils[2] It has been recorded that various seabirds, turtles, fish and whale species experience the bad effects of consumption of Plastic waste (PW) particles and from entrapment in plastic debris. Further, PW can suffocate marine flora by preventing gas trade on the ocean bottom [3] The root cause for indiscriminate dumping of PW is the cost of managing it in developing countries[4] And therefore it is necessary to upcycle PW into places where the durability and strength of PW can enhance strength of a weaker material to make PW upcycling a profitable endeavor, only this can motivate private participants in PW management. This study evaluates behavior of soil reinforced with PW. Low density polyethylene (LDPE) is the most common type of PW which is dumped in landfills and hence milk pouches and carry bags made from LDPE were shredded in different sizes and blended with soil to evaluate the effect of size and concentration of PW on California Bearing Ratio (CBR) of soil used for making road subgrade.

1.1 Soil Reinforcement with Fibers

Numerous studies have demonstrated improvement in properties and behavior of sands in combination with plastic[5][6] Coir fiber added to soft soils in concentrations of 0-1% have improved compaction, elastic modulus as well as CBR performance[7] Soil reinforced with polypropylene (PP) fiber with aspect ratios of 50, 84, and 100 demonstrated increase of 4.33%, 6.42%, and 18.03% in CBR value and the unconfined compressive strength (UCS) also improved to 7.16, 9.056, and 9.712 megapascal (MPa) respectively [8]Soil reinforced with plastic and natural fiber demonstrate that deviatoric stress for 1% concentration of natural fiber was 65 kilopascal (kPa) and that for plastic fiber was 80 kPa. At 3% concentration of fibers the deviatoric stress was 240 and 226 kPa for plastic and natural fiber. The study demonstrated superior performance of plastic fiber as compared to natural fiber[9] Expansive soil blended with 0.5 and 1% PP fiber demonstrated reduction in swell capacity of soil[10]

Sands reinforced with plastic multioriented hexa-pods improved angle of internal friction and the peak deviatoric stress and as compared to unreinforced sands[11] freezing performance of fiber-reinforced soil added with 0%, 0.5%, and 1% fibers suggest that 1% fiber reinforcement decreases the effects of freeze-thaw cycle[12] cohesive soil reinforced with glass fiber demonstrated significant improvement in soaked CBR value and secant modulus as compared to unreinforced soil[13] sands reinforced with PW percentages: 0, 0.5, 0.75 and 1.0 of the dry weight of sand demonstrate higher shear strength and penetration resistance at 0.75% concentration, further it was observed that penetration resistance of the reinforced sand increased to 9%[14] Clayey soil blended with sisal fibers demonstrated crack size reduction of 74% and surface crack reduced by 35% at 1% fiber content[15] clayey soil mixed with 1.5 % and 3.0 % PW is tougher than plain clay as it enhances shear strength and reduces volume change of plain clay[16].

Summary of Literature From the available literature it can be established that weak soils and strong soils exhibit improvements after reinforcement with fibers. Further it is observed that plastic fibers provided better enhancement as compared to natural fibers, this may be due to superior strength and durability of plastic fibers. Most of the plastic fibers were specially manufactured for reinforcement purpose and very few research papers have utilized PW fibers.

2 Experimental Investigation

To make roads sustainable it was decided to use only PW fibers for reinforcement of soil, since very few studies have been conducted on behavior of PW reinforced marine clay and fine gravel soil, the same were chosen as a study material. It was observed that most omnipresent constituent of PW in landfills were milk pouches hence they were chosen to be reinforcing material, the milk pouches were cut into filaments of 5mm width and length in the range of 20-80mm as shown in Fig. 1.

2.1 Marine clay:

Marine clay displays very poor CBR value and is mostly blended with cement or other strength enhancing agents who are economically and environmentally not suitable for large projects expensive and hence it was selected as a primary study material. Optimum moisture content (OMC) for marine clay were found to be 18.5% and maximum dry density (MDD) was 1.621 gm/cc as per IS 2720-8 [17] it was found that addition of fiber reinforcement does not affect OMC and MDD[18].

Fig. 1. Soil reinforcing filaments from Milk pouches

Un-reinforced marine clay was tested for soaked CBR value as per IS 2720-16[19] marine clay was mixed with PW fibers Fig. 2. and compacted in three layers with light compaction as shown in Fig. 3.

Fig. 2. Marine clay mixed with PW filaments

PW fibers with constant width of 5 mm and length in the range of 20 mm to 80 mm with concentrations increasing by 1% was mixed for each sample of marine clay as displayed in Table 1. CBR values obtained for various concentration and length of PW are plotted in Fig. 5. During sample preparation it was observed that up to 30 mm length the fibers were not causing any discomfort in mixing, but beyond 40 mm length and with 2% concentration the mixing effort had to be increased considerably for marine clay.

Table 1. Marine clay reinforced with PW

PW %	Length of Plastic filaments (mm)	Soaked CBR Value (%)	Load taken by sample at 2.5 mm penetration (kg)	Change in CBR Value %
0	0	0.92	12.60	0%
1	20	0.928	12.71	1%
	30	0.935	12.81	2%
	40	0.941	12.89	2%
	50	0.95	13.02	3%
	60	0.96	13.15	4%
	70	0.99	13.56	8%
	80	0.98	13.43	7%
2	20	0.941	12.89	2%
	30	0.955	13.08	4%
	40	0.968	13.26	5%
	50	0.981	13.44	7%
	60	0.991	13.58	8%
	70	1.021	13.99	11%
	80	0.965	13.22	5%
3	20	0.948	12.99	3%
	30	0.941	12.89	2%
	40	0.935	12.81	2%
	50	0.929	12.73	1%
	60	0.914	12.52	-1%
	70	0.908	12.44	-1%
	80	0.901	12.34	-2%

Fig. 3. CBR sample of PW reinforced marine clay

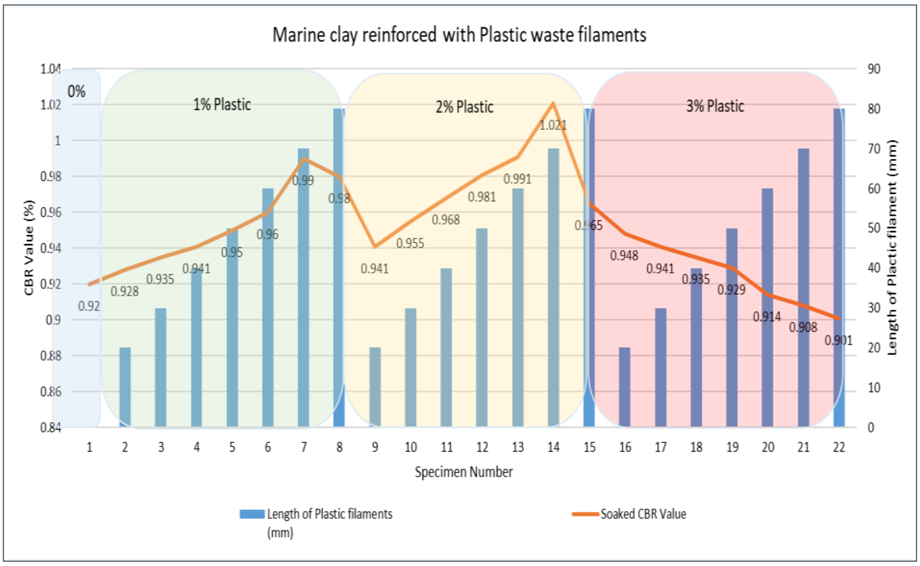


Fig. 4. Marine clay reinforced with PW

2.2 Fine gravel:

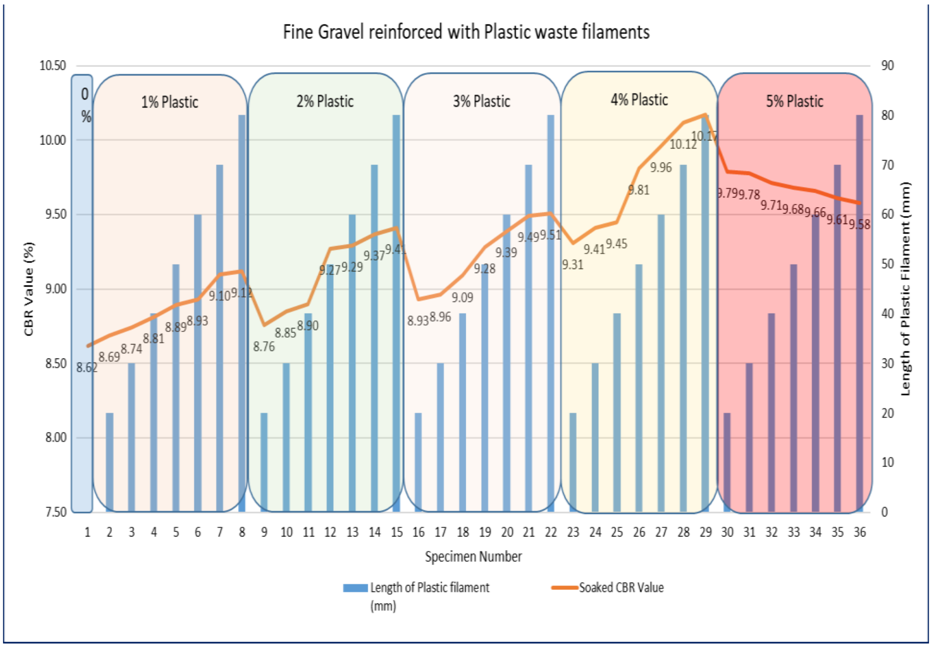
Fine gravel soil is abundant and most used subgrade material and hence it was chosen as a second study material in this investigation. Sample obtained from site was moist hence it was first air dried for 7 days and after breaking the lumps sample was oven dried for 24 hours and then was sieved through 20 mm IS sieve sample retained on 4.75 mm sieve. Its OMC and MDD were 7.7% and 1.970 gm/cc respectively.

Table 2. Fine gravel reinforced with PW

PW %	Length of Plastic filaments (mm)	Soaked CBR Value (%)	Load taken by sample at 2.5 mm penetration (kg)	Change in CBR Value %
0	0	8.62	118.09	0%
1	20	8.69	119.05	1%
	30	8.74	119.74	1%
	40	8.81	120.70	2%
	50	8.89	121.79	3%
	60	8.93	122.34	4%
	70	9.10	124.67	6%
	80	9.12	124.94	6%
2	20	8.76	120.01	2%
	30	8.85	121.25	3%
	40	8.90	121.93	3%
	50	9.27	127.00	8%
	60	9.29	127.27	8%
	70	9.37	128.37	9%
	80	9.41	128.92	9%
3	20	8.93	122.34	4%
	30	8.96	122.75	4%
	40	9.09	124.53	5%

	50	9.28	127.14	8%
	60	9.39	128.64	9%
	70	9.49	130.01	10%
	80	9.51	130.29	10%
4	20	9.31	127.55	8%
	30	9.41	128.92	9%
	40	9.45	129.47	10%
	50	9.81	134.40	14%
	60	9.96	136.45	16%
	70	10.12	138.64	17%
	80	10.17	139.33	18%
5	20	9.79	134.12	14%
	30	9.78	133.99	13%
	40	9.71	133.03	13%
	50	9.68	132.62	12%
	60	9.66	132.34	12%
	70	9.61	131.66	11%
	80	9.58	131.25	11%

The oven dried soil was mixed with water equal to OMC and CBR sample was prepared using light compaction Fig. 5. the test was performed as per IS 2720-18 [19] the same procedure was repeated for addition of plastic waste in different length and concentration as described for marine clay. Beyond 40 mm length mixing of PW with fine gravel was difficult due to resistance caused by fibers. The effect on CBR value due to variation in PW fiber length and concentration can be observed in Table 2. The results of soaked CBR of fine gravel soil was plotted in Fig. 6. There was a sharp increase in CBR value for PW longer than 40 mm for each concentration.



3 Result and Conclusions

For 1% and 2% concentration of PW the CBR value of marine clay increased for 60 to 70 mm length and started reducing as PW concentration increased, Significant drop of CBR value was observed at 3% concentration for all lengths of PW, Highest improvement in CBR value was observed at 2% concentration and 70 mm length, at optimum length and concentration of PW the CBR value was 11% higher as compared to un-reinforced specimen.

The increased CBR value of marine clay is statistically significant but still does not reach CBR value 5 which is the benchmark stated by IRC 37-18 [20] and hence even at this optimum PW level it can not be used as a subgrade material for flexible pavement.

It was observed that PW reinforcement in fine gravel gradually increased CBR value up to 4% PW concentration, beyond which the increase in PW concentration reduced the CBR value. Fine gravel reinforced with PW have demonstrated 18% improvement in CBR value as compared to un-reinforced sample. Further it is evident that 40 to 80 mm length PW fibers have given highest reinforcing action up to 4% concentration.

From this study it can be concluded that 70 to 80 mm long PW fibers at concentration of 4% by dry weight of fine gravel may be optimum reinforcement to increase the CBR value significantly making road subgrade durable and eliminate PW from landfills hence contribute to make roads sustainable.

In future sensitivity analysis between concentration and length of PW may be done to identify the significant contributor for increase in CBR value as the same is not clear from this study.

To utilize marine clay as a subgrade material it may be blended with fly ash at optimum length and concentration of PW as described in this paper to achieve desired CBR value. PW processing for soil reinforcement can be an additional source of income to PW handling small industry.

References

1. J. R. Jambeck et al., “Plastic waste inputs from land into the ocean,” Science (80-.)., vol. 347, no. 6223, pp. 768–771, Feb. 2015, doi: 10.1126/science.1260352.
2. R. Geyer, J. R. Jambeck, and K. L. Law, “Production, use, and fate of all plastics ever made,” Sci. Adv., vol. 3, no. 7, p. 1700782, Jul. 2017, doi: 10.1126/sciadv.1700782.
3. S. Chaturvedi, B. P. Yadav, N. A. Siddiqui, and S. K. Chaturvedi, “Mathematical modelling and analysis of plastic waste pollution and its impact on the ocean surface,” J. Ocean Eng. Sci., vol. 5, no. 2, pp. 136–163, Jun. 2020, doi: 10.1016/j.joes.2019.09.005.
4. A. Antelava et al., “Plastic Solid Waste (PSW) in the Context of Life Cycle Assessment (LCA) and Sustainable Management,” Environ. Manage., vol. 64, no. 2, pp. 230–244, Aug. 2019, doi: 10.1007/s00267-019-01178-3.
5. C. Benson and M. Khire, “Reinforcing sand with strips of reclaimed high-density polyethylene,” J. Geotech. Eng., vol. 121, no. 4, pp. 399–401, 1995, doi: 10.1061/(ASCE)0733-9410(1995)121:4(399).
6. R. K. Dutta and G. V. Rao, “Engineering Properties of Sand Reinforced with Strips from Waste Plastic,” no. January 2004, pp. 186–193, 2004.
7. L. Peter, P. K. Jayasree, K. Balan, and S. A. Raj, “Laboratory Investigation in the Improvement of Subgrade Characteristics of Expansive Soil Stabilised with Coir Waste,” Transp. Res. Procedia, vol. 17, no. December 2014, pp. 558–566, 2016, doi: 10.1016/j.trpro.2016.11.110.

8. S. Chandra, M. N. Viladkar, and P. P. Nagrale, "Mechanistic approach for fiber-reinforced flexible pavements," J. Transp. Eng., vol. 134, no. 1, pp. 15–23, 2008, doi: 10.1061/(ASCE)0733-947X(2008)134:1(15).
9. A. Chegenizadeh and H. Nikraz, "Performance of fiber reinforced clayey sand composite," Front. Struct. Civ. Eng., vol. 6, no. 2, pp. 147–152, 2012, doi: 10.1007/s11709-012-0158-6.
10. M. Malekzadeh and H. Bilsel, "Hydro-mechanical behavior of polypropylene fiber reinforced expansive soils," KSCE J. Civ. Eng., vol. 18, no. 7, pp. 2028–2033, 2014, doi: 10.1007/s12205-014-0389-2.
11. M. Harikumar, N. Sankar, and S. Chandrakaran, "Response of Sand Reinforced with Multi-Oriented Plastic Hexa-Pods," Soil Mech. Found. Eng., vol. 52, no. 4, pp. 211–217, 2015, doi: 10.1007/s11204-015-9330-z.
12. M. E. Orakoglu and J. Liu, "Effect of freeze-thaw cycles on triaxial strength properties of fiber-reinforced clayey soil," KSCE J. Civ. Eng., vol. 21, no. 6, pp. 2128–2140, 2017, doi: 10.1007/s12205-017-0960-8.
13. S. K. Patel and B. Singh, "Experimental Investigation on the Behaviour of Glass Fibre-Reinforced Cohesive Soil for Application as Pavement Subgrade Material," Int. J. Geosynth. Gr. Eng., vol. 3, no. 2, pp. 1–12, 2017, doi: 10.1007/s40891-017-0090-x.
14. R. E. Farah and Z. Nalbantoglu, "Performance of plastic waste for soil improvement," SN Appl. Sci., vol. 1, no. 11, pp. 1–7, 2019, doi: 10.1007/s42452-019-1395-2.
15. I. Kafodya and F. Okonta, "Desiccation Characteristics and Desiccation-Induced Compressive Strength of Natural Fibre-Reinforced Soil," Int. J. Geosynth. Gr. Eng., vol. 5, no. 3, pp. 1–14, 2019, doi: 10.1007/s40891-019-0169-7.
16. H. Soltani-Jigheh, "Compressibility and shearing behavior of clayey soil reinforced by plastic waste," Int. J. Civ. Eng., vol. 14, no. 7, pp. 479–489, 2016, doi: 10.1007/s40999-016-0068-4.
17. B. of Indian Standards, "IS 2720-8 (1983): Methods of test for soils, Part 8: Determination of water content-dry density relation using heavy compaction."
18. A. Ekinci and P. M. V Ferreira, "The undrained mechanical behaviour of a fibre-reinforced heavily over-consolidated clay."
19. B. of Indian Standards, "IS 2720-16 (1987): Methods of test for soils, Part 16: Laboratory determination of CBR.".
20. IRC, Guidelines for The Design of Flexible Pavements Indian Roads Congress.