Laboratory Study on the Effect of Plastic Waste Additive on Shear Strength of Marginal Soil

B. A. Mir

Abstract The shear strength of marginal soils can be enhanced by means of stabilization methods using various additives or waste materials. Among various waste materials, plastic bottles and carry bags are tremendously used and thrown away as a waste material onto the ground, which being non-biodegradable material pollutes the environment. Therefore, for an eco-friendly and sustainable environment, there is a dire need for proper use of plastic waste as an admixture in various engineering applications. In this paper, investigation has been carried out to enhance the engineering characteristics of Campus soil by randomly mixing with the plastic strips/chip of different aspect ratios and proportions (0.25, 0.75, 1 and 1.5%) by weight of dry soil. A series of laboratory tests consisting of compaction, CBR and shear strength tests were conducted on composite samples. The test results showed that the addition of 1% plastic waste material with aspect ratio of 3 enhanced the shear strength and California bearing ratio (CBR) of the Campus soil. It was also concluded that base course thickness of a road pavement can be significantly reduced if plastic waste strips are used as soil stabilizing agent for sub-grade material for flexible pavements in highway sub-base construction.

Keywords Marginal soils · Waste materials · Soil stabilization · Sustainable environment

1 Introduction

Plastic waste is being increased many-fold day by day due to rapid increase in industrialization and its peculiar characteristics such as leak proof and light weight. The plastic bottles of transparent polyethylene terephthalate (PET) material are commonly used for mineral water, soda waters, soft drinks, oil containers, etc. The large quantity of plastic waste is generally produced in the form transparent polyethylene terephthalate (PET) bottles, low-density polyethylene (LPDE) bags, high-density

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(a) Types of plastic wastes

(b) Disposal and environmental problems imposed by plastic wastes

Fig. 1 Types of plastic wastes and disposal problems

polyethylene (HDPE) containers and bottles, polypropylene (PP) foil bags, expanded polystyrene (EPS) sheets, food containers and wrappers, PVC and plastic bags used for transport and packing materials, etc. (Fig. 1a). However, plastic wastes are non-biodegradable and pollute the environment causing severe health problems (Fig. 1b). Therefore, there is a dire need for scientific use of this non-biodegradable waste in various geotechnical applications for sustainable environment. This plastic waste can be used as source material for thermal insulation.

Among various plastic wastes, the bottled water is the fastest growing beverage industry in the world and about more than 2 million tons of plastic is used to bottle water every year [15]. Thus, the huge quantity of plastic waste not only requires lot of land for its disposal, but also pollutes the environment. Therefore, there is a dire need for characterization of such waste materials for improvement of marginal soil deposits to be used either as foundation medium or as an engineered construction material for building various infrastructures. Thus, for a sustainable development of environment, there is dire need for proper use of plastic waste as an additive in various engineering applications. Unlike other additives such as fly ash, fibre reinforcement and human hair [8, 18–20, 24, 26], plastic waste has also been a promising material to improve locally available marginal soils as well as enhances the properties of stabilized soils [21]. Many researchers (e.g. Ghavami et al. [14], Consoli et al. [9, 10]) have concluded that plastic waste in the form of polyethylene terephthalate fibre when added to marginal soils improved the engineering properties significantly. Peddaiah et al. [23] investigated the effectiveness of polyethylene terephthalate (PET) in improving the behaviour of silty sand and concluded that the engineering properties were considerably improved. They further concluded that both shear strength parameters increased using roughed surface plastic strips. Similar results were also reported by Nsaif [22] and Mercy Joseph et al. [16]. Dutta and Rao [13] have reported that adding LDPE strips to locally marginal soils increased load bearing capacity of soil to support design maximum loads. Choudhary et al. [11] used high-density polyethylene (HDPE) for improvement of weak soils to enhance the engineering properties of sub-grade soil. Thus, the weak/marginal soils could be significantly improved effectively admixed with plastic wastes. Therefore, in this paper, an attempt was made to utilize waste plastic bottle (PET bottle) strips/chips by randomly mixing with clayey soil to investigate the suitability of plastic waste as an additive for stabilization of marginal soils.

2 Environmental Issues and Sustainability Aspects

Environment is lifeline of livelihood for all living species and any sort of exploitation with its resources will imbalance life cycle of all living species. Since due to rapid urbanization and increase in population, lot of waste material is produced every day. If the waste material is not disposed off scientifically, it will create severe health and environmental problems. Since the environmental issues are multidimensional and dynamic, researchers, designers and engineers should adopt sustainable engineering practices, which can meet the human aspirations and needs for natural environmental balance and effective waste material management and utilization.

3 Materials

3.1 Soil Samples

In the present study, soil samples were collected from three locations in the Institute Campus (henceforth termed as Campus soil). At each site, soil samples were collected, sealed and transported with utmost precaution for studying their in situ properties. All the required tests on undisturbed and disturbed (remoulded) soil samples were conducted base on Codal procedures (IS 2720 part 3 (10, 4, 6, 7, 10 & 16) [1–7]).

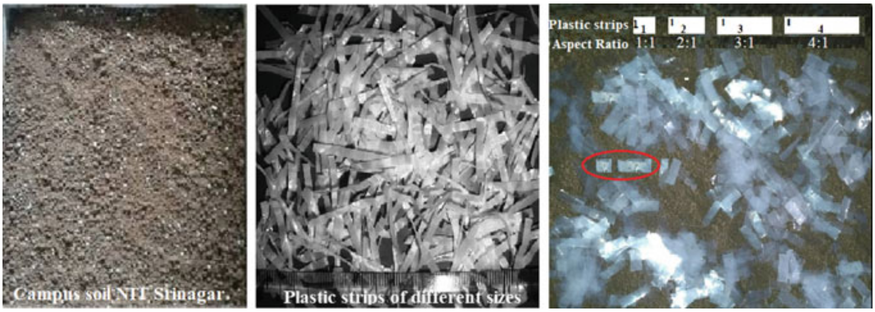

Fig. 2 Soil and plastic material used in the study

3.2 Plastic Material

In this study, the plastic material was collected from solid waste disposal site of NIT Srinagar Campus. It was mainly low-density polyethylene (LDPE).

4 Experimental Program and Methodology

In this study, all the basic tests were conducted on the untreated Campus soil as per standard codal procedure (IS 2720). After analysing the test results, the weakest sample was chosen out of three samples tested for stabilization with plastic waste. The plastic strips were cut into lengths of 10 mm (aspect ratio: AR = 1:1), 20 mm (AR = 2:1), 30 mm (AR = 3:1) and 40 mm (AR = 4:1) as shown in Fig. 2. During testing of composite test specimens, it was ensured that there is no boundary influence and the plastic strips deform freely. The plastic strips were added by weight of dry soil in different proportions so as to achieve an optimum plastic content for stabilization of marginal soils. The CBR and strength tests were carried out at different plastic strip contents of 0.25%, 0.75%, 1% and 1.5% by weight of dry soil, respectively.

5 Test Results and Discussions

5.1 Physical and Index Properties of Campus Soil

The soil samples collected from three locations were analysed as per IS 1470-1948. The specific gravity tests of these soil samples were carried out as per IS 2720-part 3. A series of trials were taken on the three samples, and the average values of specific gravity are 2.60 for JH, 2.62 for JKB and 2.61 for MED sites, respectively. It was observed that the test specimens exhibit lower specific gravity than standard value of 2.65 for natural soils. The soil grading (IS 2720-part 4) for Campus soils was carried out as per standard codal procedures (Fig. 3). From Fig. 3, it is observed that the Campus soil is fine-grained dominated by silt content. Atterberg limits such as liquid limit, plastic limit and shrinkage limits for the Campus soils were determined in accordance with IS 2720-part 5. From the test results, the Campus soil is classified as clayey soil with medium plasticity. It is also seen that the soil collected from Jhelum Hostel (JH) site is weaker than other two soil samples having higher rate of loss of shear strength (Fig. 4).

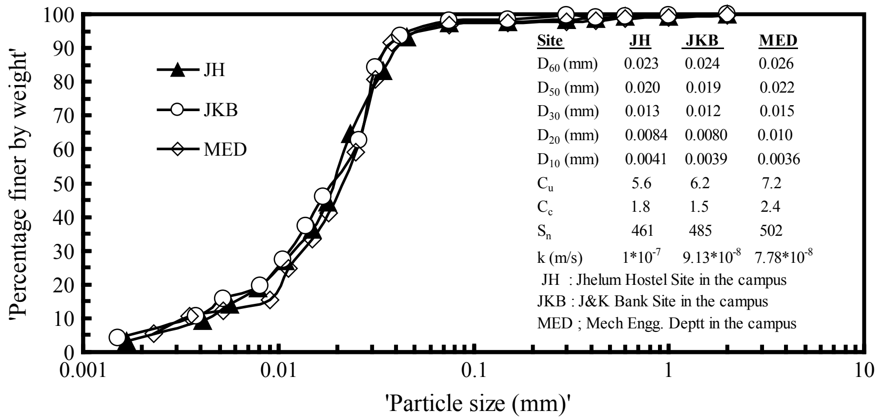

Fig. 3 Particle size distribution curves for Campus soils, NIT Srinagar

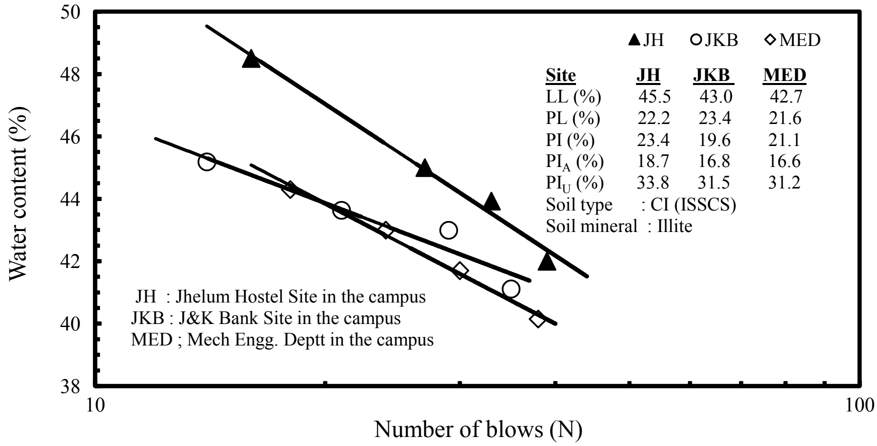

Fig. 4 Flow curves for Campus soils, NIT Srinagar

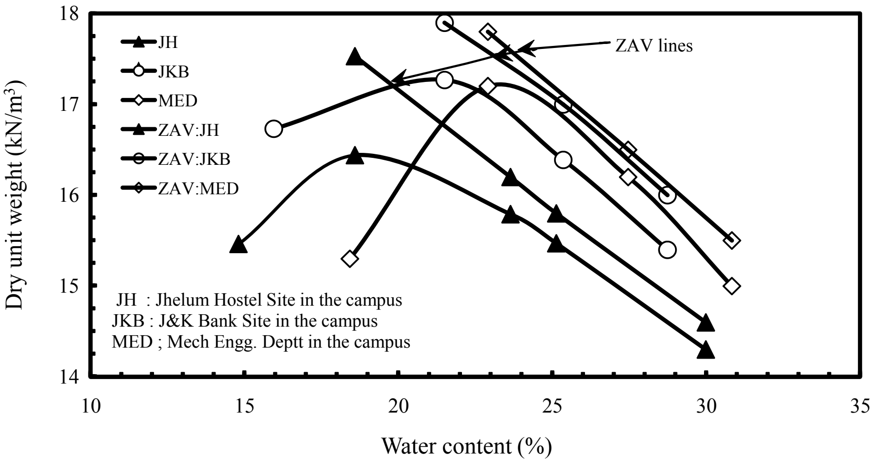

Fig. 5 Compaction curves for Campus soils, NIT Srinagar

5.2 Compaction Characteristics of the Campus Soil

The standard compaction tests were conducted to determine the compaction characteristics such as optimum moisture content (OMC) and the maximum dry unit weight (MDU) for all the three soil samples (JH, JKB and MED) (IS 2720-part 7) as shown in Fig. 5. From Fig. 5, the values of optimum moisture content and maximum dry unit weight obtained are 19%, 21.7%, 23.6% and 16.4 kN/m^3, 17.2 kN/m^3, 17.1 kN/m^3, respectively. Since the dry unit weight is relatively less as expected for stable soil deposits (generally >17.5 kN/m^3), the soil need to be improved for sustainable construction of infrastructures.

5.3 Effect of Plastic Stabilization on California Bearing Ratio (CBR)

Among the available methods of design of flexible pavements, the California bearing ratio (CBR) method is the most reliable method of evaluating the strength of the sub-grade material [17]. In this study, plastic strips were blended with the soil and then mixed thoroughly until homogeneous mix was obtained. A series of unsoaked and soaked CBR tests were conducted on plastic stabilized soil samples and the load penetration curves are shown in Figs. 6 and 7, respectively. From Fig. 6a, it is observed that unsoaked CBR increases with the addition of plastic strips in different proportions and aspect ratios. The test results showed that maximum value of CBR is obtained for an optimum plastic content of 1% with an aspect ratio of 3:1. On increasing aspect ratio beyond 3, the CBR values decreased. This may be attributed

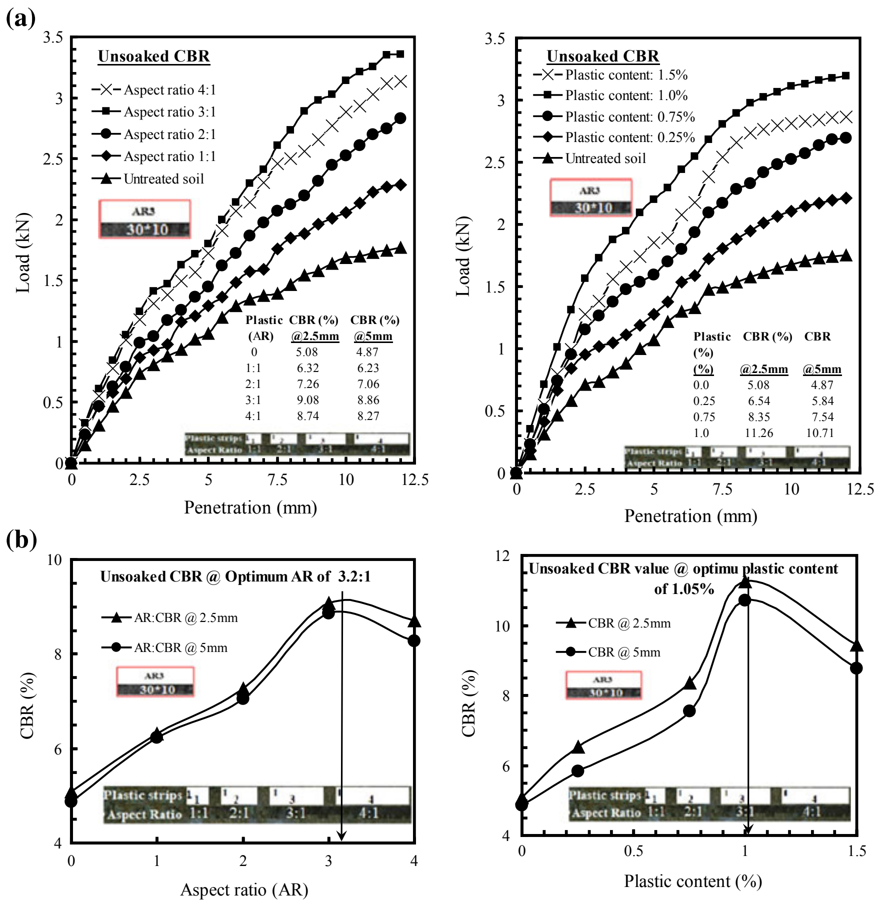

Fig. 6 **a** Unsoaked CBR curves for stabilized campus soil, NIT Srinagar. **b** Variation of unsoaked CBR with aspect ratio and plastic content

due to the fact that plastic strips interaction is more slippery than soil–soil interaction. The higher aspect ratio of plastic strips results in decrease of frictional resistance and hence lowers CBR of composite soil. The variation of unsoaked CBR with aspect ratio and plastic content is shown in Fig. 6b. Similar trend is observed for soaked CBR tests as illustrated in Fig. 7a, b. Similar results have also been reported by Craig and Khire [12], Mir [17] and Rawat and Kumar [25].

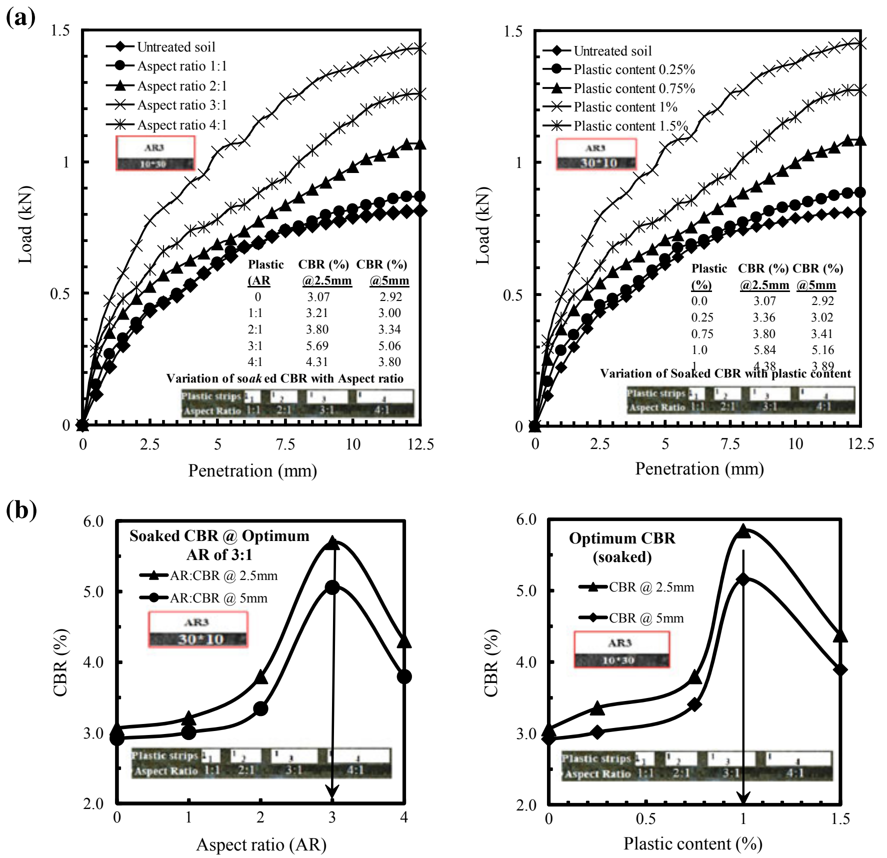

Fig. 7 **a** Soaked CBR curves for stabilized campus soil, NIT Srinagar. **b** Variation of soaked CBR with aspect ration and plastic content

5.4 Effect of Plastic Waste Content on the Unconfined Compressive Strength

In this paper, the unconfined compression tests were conducted on plastic admixed soil specimens as per IS 2720-part-10 for "Immediate" test series under a constant strain rate of 0.625 mm/min. In both cases, the composite test specimens of height 7.6 cm and diameter 3.8 cm were prepared by statically compacting the mixtures in a mould at 0.95 $\gamma_{d\max}$ and corresponding water content dry side of optimum. The effect of increasing plastic content with aspect ratio of 3 on stress–strain behaviour of composite soil specimens is illustrated in Fig. 8. From test results, it is seen that the unconfined compressive increases with addition of plastic content. The test results showed that the maximum value of UCS is obtained for 1% plastic content with an aspect ratio of 3:1. On increasing plastic content 1%, the UCS values decrease.

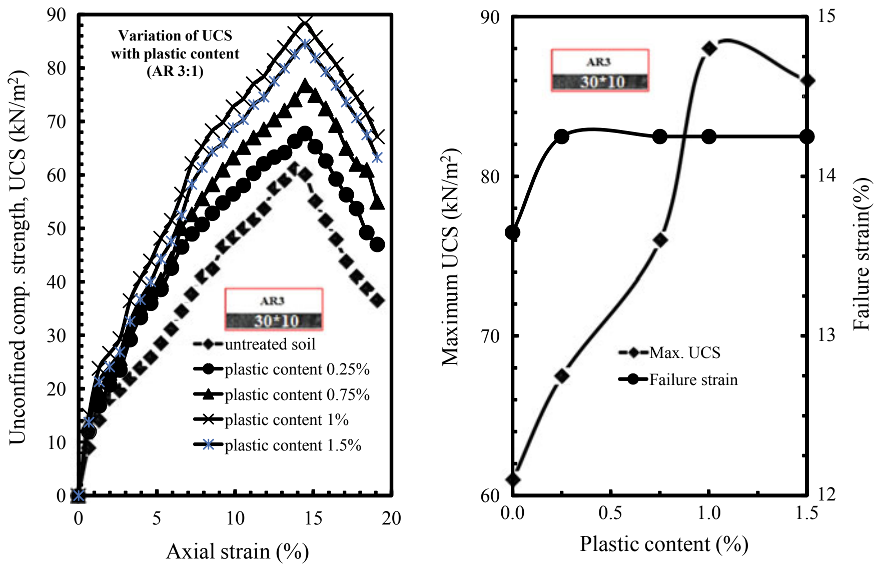

Fig. 8 Variation of unconfined compressive strength with plastic content

However, there is a negligible effect on failure strain, which remains constant with increasing plastic content. This may be attributed due to the fact that plastic strips crossing the failure plane increase and resistance towards the deformation of soil along the failure plane enhances the failure strain.

6 Conclusions

Based on the test results and discussions, the following conclusions can be made:

1. The CBR values of the Campus soil are significantly altered by the addition of plastic waste material in the form of different proportions and aspect ratios.
2. The extent of variation depends on the aspect ratio and the plastic content. A proper mix proportion improves the CBR and shear strength values.
3. It has been observed that 1% of plastic content with an aspect ratio of 3 is the optimum amount required to maximize the CBR and shear strength of the Campus soil.
4. The thickness of sub-grade can be reduced significantly by way of mixing soils with suitable amount of LDPE strips.
5. Thus, a marginal soil with the proper quantity of plastic waste is recommended for use in various geotechnical works for sustainable environment and cost-effective infrastructures.

Future Scope of Work

For complete characterization of marginal soils and stabilization with plastic waste material as an additive, further tests such as permeability, consolidation and triaxial tests need to be performed to study the final behaviour of plastic reinforced soil.

References

1. Bureau of Indian Standards (1970) IS 1498: classification and identification of soils for general engineering purposes. Bureau of Indian Standards, New Delhi
2. Bureau of Indian Standards (1980) IS 2720-part 3(1): determination of specific gravity of fine grained soils. Bureau of Indian Standards, New Delhi
3. Bureau of Indian Standards (1985) IS 2720-part 4: determination of grain size distribution. Bureau of Indian Standards, New Delhi
4. Bureau of Indian Standards (1985) IS 2720-part 5: determination of Atterberg limits. Bureau of Indian Standards, New Delhi
5. Bureau of Indian Standards (1980) IS 2720-part 7: determination of water content-dry density relation using light compaction. Bureau of Indian Standards, New Delhi
6. Bureau of Indian Standards (1979) IS 2720-part 16: laboratory determination of CBR. Bureau of Indian Standards, New Delhi
7. Bureau of Indian Standards (1986) IS 2720-Part 10: laboratory tests procedure for unconfined compressive strength test. Bureau of Indian Standards, New Delhi
8. Butt WA, Mir BA, Jha JN (2016) Strength behaviour of clayey soil reinforced with human hair as a natural fibre. Geotech Geol Eng 2016(34):411–417
9. Chouksey SK, Babu GLS (2011) Stress-strain response of plastic waste mixed soil. Waste Manage (New York NY) 31(3):481–488
10. Consoli NC, Montardo JP, Prietto PDM, Pasa GS (2002) Engineering behaviour of a sand reinforced with plastic waste. J Geotech Geoenviron Eng ASCE 128(6):462–472
11. Choudhary AK, Jha JN, Gill KS (2010) A study on CBR behaviour of waste plastic strip reinforced soil. Emir J Eng Res 15(1):51–57
12. Craig HB, Khire MV (1994) Reinforcing sand with strips of reclaimed high density polyethylene. Jr Geotech Eng 120(5):838–855
13. Dutta R, Rao GV (2004) Ground improvement with plastic waste. In: Proceeding 5th international conference on ground improvement technique, Kaulalumpur, Malaysia, pp 321–328
14. Ghavami K, Filho R, Barbosa P (1999) Behaviour of composite soil reinforced with natural fibres. Cement Concr Compos 21:39–48
15. Maurya R, Kumar U (2015) Utilization methods of polymer waste in geotechnical applications. Int J Sci Res Publ 5(10):1–7
16. Mercy Joseph P, Haneef FM, Jacob MT, Krishnan R, Rajan S (2014) Effect of plastic granules on the properties of soil. Int J Eng Res Appl 4(4):160–164
17. Mir BA (2005) Effect of dredged material on the CBR behaviour of fine grained soils. In: Proceedings of international conference on structural and road transportation engineering (START 2005). Elite Publishing House Pvt Ltd., New Delhi, pp 542–550
18. Mir BA, Sridharan A (2013) Physical and compaction behaviour of clay soil–fly ash mixtures. Geotech Geol Eng 31(4):1059–1072
19. Mir BA (2015) Some studies on the effect of fly ash and lime on physical and mechanical properties of expansive clay. Int J Civil Eng Trans B: Geotech Eng-Geotech 13(3&4B):203–212
20. Mir BA, Sridharan A (2019) Mechanical behaviour of fly ash treated expansive soil. In: Proceedings of the institution of civil engineers-ground improvement, vol 172, no 1. ICE-UK, pp 12–24

21. Muntohar AS (2009) Influence of plastic waste fibers on the strength of lime-rice husk ash stabilized clay soil. Civil Eng Dimens 11(1):32–40
22. Nsaif MH (2013) Behaviour of soils strengthened by plastic waste materials. J Eng Dev 17(4):182–194
23. Peddaiah S, Burman A, Sreedeep S (2018) Experimental study on effect of waste plastic bottle strips in soil improvement. Geotech Geol Eng 36(5):2907–2920
24. Puppala AJ, Musenda C (2000) Effects of fibre reinforcement on strength and volume change in expansive soils. Transp Res Rec TRB 1736(2000):134–140
25. Rawat P, Kumar A (2016).Study of CBR behaviour of soil reinforced with HDPE strips. In: Proceedings of Indian geotechnical conference IGC 2016. IIT Chennai, pp 1–4
26. Tang CS, Shi B, Gao W, Chen FJ, Cai Y (2007) Strength and mechanical behaviour of short polypropylene fiber reinforced and cement stabilized clayey soil. Geotext Geomembr 25:194–202