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Influence of Crumb Rubber and Polypropylene Fibre on the Behaviour of Cemented Black Cotton Soil

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Abstract. Research was being carried-out all over the world on expansive soils to mitigate their problematic behaviour and suggested various ground improvement techniques in the recent times among which chemical stabilization is quite popular. In this stabilization process, the soil is mixed with cement, lime and several industrial reactive by-products such as, fly ash, bagasse ash, etc., have been used for stabilization of soil in weak deposits. Even unreactive by products like crumb rubber and polypropylene which are produced from scrap tyre and polymers respectively are also being utilized that reduces the burden on landfills. In this study, crumb rubber and polypropylene were used to assess the modification in geotechnical properties of a lime cemented black cotton soil. The geotechnical properties of virgin soil were determined and a lime content of 4% which was fixed for carrying out subsequent experiments based on the pH test and the Atterberg limits. A 0.25% polypropylene content and varied crumb rubber contents of 0, 1, 2, 5 and 10% was added to the lime cemented soil in order to find the optimum dosage using the unconfined compressive strength (UCS) testing. Based on the test results, 5% crumb rubber was found to be the optimum content that could be effectively used to improve the strength.
Keywords: Crumb Rubber, Polypropylene, Blending.

1 Introduction

The Indian Black Cotton (BC) soils are well known for their expansive behaviour and appears predominantly in black colour which is abundantly used for cotton crops. These soils cover about one-fifth of the total land area in India [23]. With the ever-growing population and the infrastructure needs of the society, it becomes almost impossible to carry-out construction activities only on the limited good soils that offers adequate strength and reliability [21]. Carrying out the construction activities on these BC soils results in severe damage of structures which can be easily observed in the walls. Several researchers across the globe studied the volume change behaviour of the expansive soils and provided various ground improvement techniques to mitigate the excessive swell-shrink behaviour [18, 20, 25, 26, 32]. Besides swell-shrink behaviour, the BC soils are also possess very low strength and the research has been carried out in improving the strength of the BC soil by chemical modification [20, 27, 32, 35, 39], by inclusion of various kinds of natural [5, 7, 18] and artificial fibres [1, 5, 19, 23, 27, 30].

The ground improvement techniques not only help in modifying the existing poor soils but also providing basis for utilization of a lot of wastes and industrial byproducts that require a lot of inputs in terms of cost and space [34]. Research has been initiated in recent years in utilizing this geotechnical engineering arena for effective utilization of plastic wastes [33, 37] and rubber wastes [12, 22, 29]. The utilization of rubber wastes in the ground improvement applications offer not only in effective disposal of wastes but also additional advantages of being the light weight material [10, 11] and high damping efficiency in earthquake engineering applications [24, 28, 38]. Inclusion of tyre material in the clayey soil improves the load carrying capacity of soil [4]. The amount of improvement in the strength, quantity of material and the durability are some important factors to be considered in soil-rubber mixtures [31, 40].

Several studies have shown that there is an optimum lime content up to which the increase in strength is marginal and later which it decreases [3, 6, 9]. For further improvement in lime stabilized soil, additional treatment can be done by reinforcing the material with some non-reactive materials [36, 39]. Several studies were carried out on lime-fibre mixtures and rubber mixed with cemented soils. In this study, an attempt is made to check the effect of blended polypropylene fibres & crumb rubber on the compaction and strength behaviour of lime cemented black cotton soil.

2 Materials

2.1 Soil

The BC soil sample used in the current study was collected from Alampur town, Gadwal District of Telangana, India. Based on the physical observation, it was found to be black cotton soil. The soil was tested for its basic properties as per IS:2720 [13-17] and were presented in the table 1 and the grain size analysis was presented in figure 1.

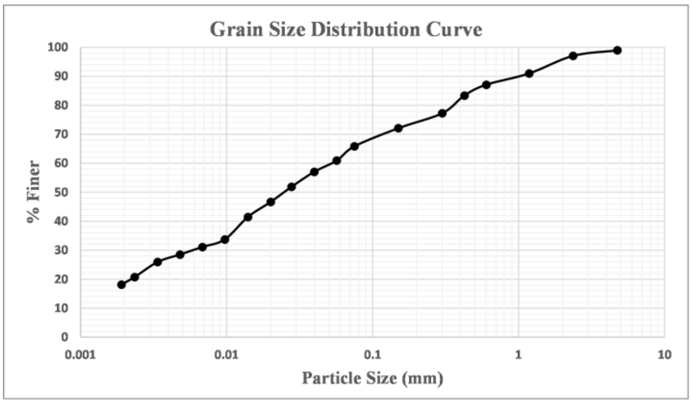

Fig. 1. Grain Size Distribution of Soil Sample.

Table 1. Soil Properties.

Sl. No.	Property	Value
1.	Specific Gravity, G	2.73
2.	Grain Size Analysis:	
	Gravel (%)	1.05
	Sand (%)	33.13
	Fines (%)	65.28
3.	Atterberg's Limits	
	Liquid Limit, LL (%)	68.3
	Plastic Limit, PL (%)	19.29
	Plasticity Index, PI (%)	49.01
4.	Indian Standard Soil Classification	CH
5.	Differential Free Swell Index (%)	65%
6.	Compaction Characteristics:	
	Optimum Moisture Content, OMC (%)	19.5
	Maximum Dry Density, MDD (%)	1.41
7	Unconfined Compressive Strength (kPa)	53.5

2.2 Lime

The negatively charged surface of the fine clayey particles absorbs the free calcium ions from the lime resulting in the alteration of the mineralogy of the particles. At higher concentrations of Ca^{2+}, isomorphous substitution takes place resulting in an increased strength of the soil because of pozzolanic reactions and formation of cementitious products. Lime addition to the highly reactive clay minerals not only increases the strength but also reduces the swell-shrink behaviour as the mineralogy itself gets altered. Commercially available hydraulic lime was used for the study.

2.3 Polypropylene fibres

Polypropylene, a monomer of petroleum-based polymer, propylene, is a 100% synthetic fibre which is transformed from 85% polypropylene. Polypropylene is thermoplastic, white, mechanically rugged material, and is resistant to many chemical solvents, acids and bases. The polypropylene to be used in this study was obtained from the local market.

2.4 Crumb rubber

Crumb rubber is a granular form of rubber recycled from the truck scrap tyres and automotive. The tyre cord (fluff) and the steel are removed from the tyre rubber during the recycling process, leaving a granular consistency material. The crumb rubber was procured from the locally available market and used for the study. The gradation of tyre crumbles was found equivalent to poorly graded sand (SP) as per I.S. Classification. Mixing crumb rubber with the clayey soil is similar to replacement of some portion of clayey soil with granular material. In the virgin soil and the cemented soil, the bond between the clayey particle and the crumb rubber could be studied with the help of microstructural analyses which was out of the scope of current study.

3 Experimental Methodology

In this study, blended polypropylene fibres and crumb rubber are used to reinforce the lime cemented BC soil. The methodology adopted for this study is as explained below:

3.1 Crumb rubber reinforcement

In the current study, the BC soil was mixed with varying percentages of crumb rubber i.e., 0, 0.5, 1, 2, 5 and 10% by weight of soil. The OMC and MDD of the respective specimens were respectively calculated and the specimens were prepared for testing.

3.2 Lime treatment

The BC soil was mixed with the optimum lime content which is found based on the initial lime consumption value found from pH test as per ASTM D6276 [2]and the Atterberg limits as per IS:2720 [14]. The compaction characteristics of the lime cemented BC soil are found by carrying out the Light compaction test as per IS:2720 [15]. The Unconfined Compressive Strength (UCS) value of the cemented soil was found as per IS:2720 [16] by preparing the specimens at OMC and MDD obtained and curing them in desiccators for 7, 14 and 28 days respectively.

3.3 Lime + crumb rubber reinforcement

The crumb rubber was added along with 4% Lime into the BC soil at varying percentages of 0.5, 1, 2, 5 and 10% by weight of soil. The OMC and MDD of all the mixtures were respectively calculated and specimens were prepared for testing. The UCS value of the specimens were found after 7, 14 and 28 days curing in desiccator.

3.4 Lime + polypropylene + crumb rubber reinforcement

The lime cemented BC soil was further reinforced with short discrete polypropylene fibres of 12mm length. An optimum of 0.25% is chosen as fibre content based on the available literature [19, 35, 36]. The OMC and MDD of reinforced lime cemented soil was found and the specimens were prepared for UCS testing at 7, 14 and 28 days curing in desiccator.

Furthermore, the lime cemented BC soil was mixed with varying percentages of crumb rubber at 0, 0.5, 1, 2, 5 and 10% by weight of the BC soil plus 0.25% polypropylene respectively. The OMC and MDD of all the mixtures were found and the specimens were prepared for UCS testing at 7, 14 and 28 days curing in desiccator.

4 Results and Discussion

The results of various tests conducted as discussed in the methodology were described in the following sub-sections. In the subsequent sections, BC stands for Black cotton soil, L stands for hydraulic lime, PP stands for polypropylene and CR stands for Crumb Rubber.

4.1 Lime treatment

The initial lime consumption value was found using the pH testing on the lime mixed soil and the Atterberg's limit tests whose results were shown in figure 2 and figure 3 respectively. Based on the results of these tests, it was identified that 4% hydraulic lime could be sufficient to modify the behaviour of BC soil. At this lime content, the soil obtained a pH value of about 12.4 which is suggesting that long term stabilization reactions could be achieved and also the soil is behaving almost non-plastic (PI=6%). The UCS of the lime modified soil was found to be 263.9kPa after 28 days curing which is about 490% of that of the virgin soil.

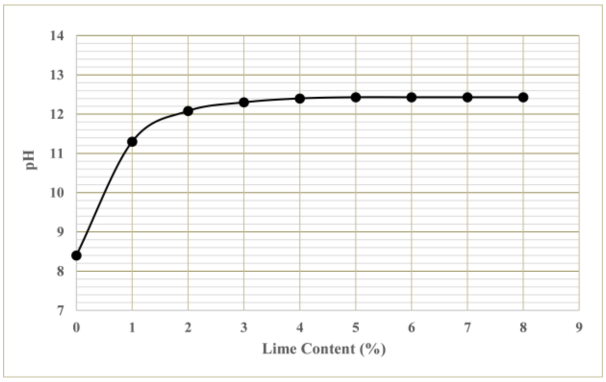

Fig. 2. Variation of pH of soil with Different Hydraulic Lime Content.

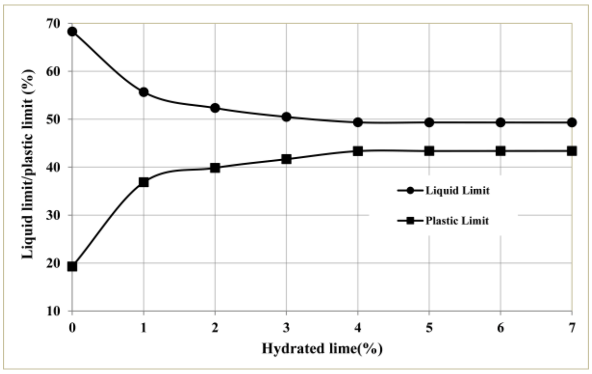

Fig. 3. Variation of Atterberg's Limits with Different Hydraulic Lime Content.

4.2 Crumb rubber reinforcement

The results of the UCS test on the BC soil mixed with varying percentages of crumb rubber were presented in figures 4 and 5. Based on the test results, it was observed that the UCS value of the BC soil increased with the addition of the CR up to 5% and then decreased with maximum value being 149.1kPa which is about 280% of that of the original soil. The initial modulus of elasticity was not found to be varied much except in case of 1% CR addition.

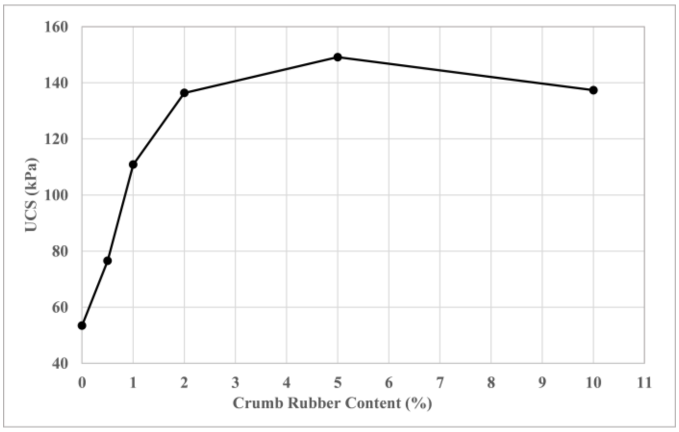

Fig. 4. UCS values of BC+CR Mixtures.

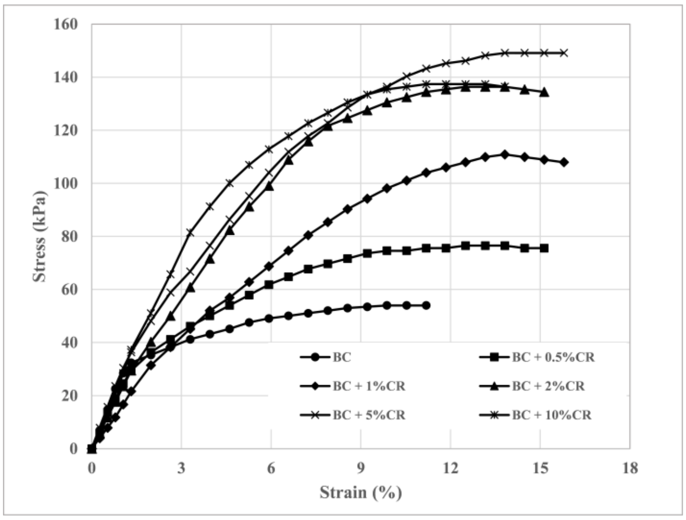

Fig. 5. Stress vs. Strain curves for BC+CR mixtures.

4.3 Lime + Crumb rubber reinforcement

The UCS test results of the lime modified BC soil mixed with varying percentages of CR were presented in the figure 6 and the average stress vs. strain variations of different specimens after 28 days curing were presented in figure 7. Examination of test results provides a basic understanding of the improvement possible with the rubber crumbles added together with lime. The strength of the BC+4%L+CR samples shown a similar trend as in the case only BC+CR mixtures giving the maximum strength at 5% CR addition. An increase in the UCS value, after 28 days curing, of about 700% and 140% was observed compared to that of virgin BC soil and 28 days strength of BC+4%L mixture respectively.

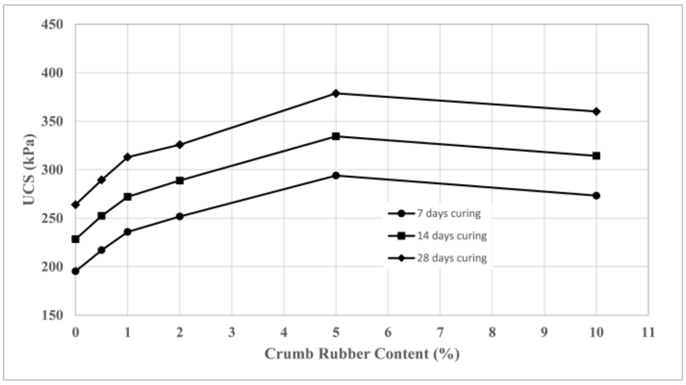

Fig. 6. UCS values of BC + 4%L + CR Mixtures.

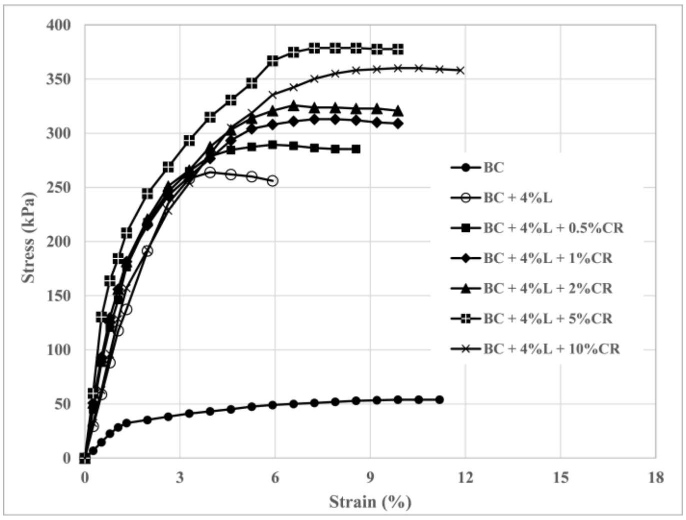

Fig. 7. Stress vs. Strain curves for BC + 4%L + CR Mixtures.

4.4 Lime + Polypropylene + Crumb rubber reinforcement

Furthermore, a little strength increase was observed when the PP and CR was blended together with the Lime and BC soil which can be seen from figure 8. The stress strain variation of these specimens after 28 days curing were presented in figure 9 which shows the improvement in the initial modulus of elasticity with PP reinforcement in BC+4%L mixture and further similar increase with CR blending. 5%CR addition was found to optimum value giving the highest UCS value. This value corresponds to about 920%, 188% and 130% times that of the Virgin BC soil, BC+4%L and BC+4%L+0.25%PP mixtures after 28 days curing.

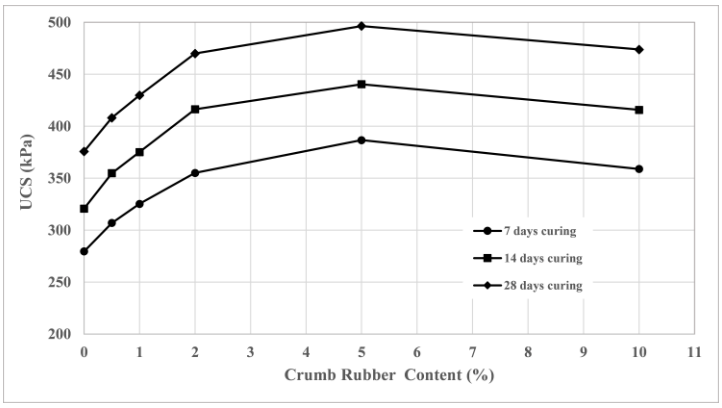

Fig. 8. UCS values of BC + 4%L + 0.25%PP + CR Mixtures.

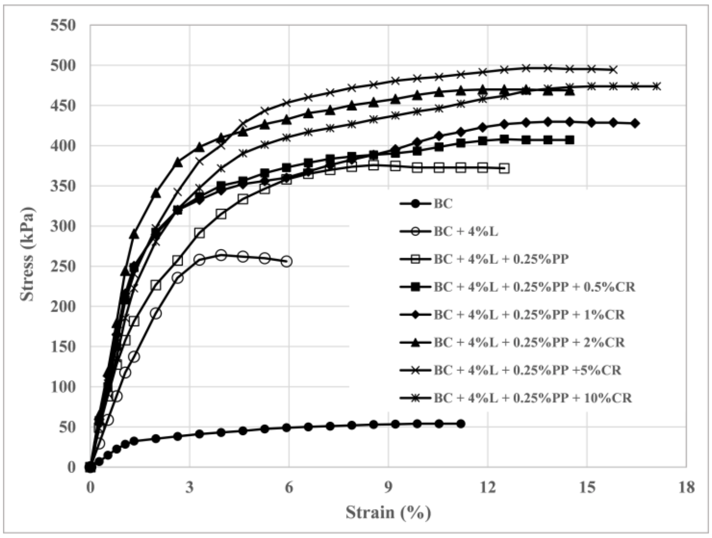

Fig. 9. Stress vs. Strain curves for BC + 4%L + 0.25%PP + CR Mixtures.

5 Conclusions

Tyre being a hazardous industrial waste requires a lot of available land for its disposal. Geotechnical engineering applications being a suitable option for bulk use of these materials, it is very important to study their applicability. Hence, a series of tests were performed to study the effect of the randomly distributed CR and discrete short PP fibres on the strength of the uncemented and lime cemented soil. The addition of CR to the virgin soil and the lime modified soil resulted a noticeable increment in the UCS values. Increasing CR content increased the strength up to 5% and then got reduced which shows that 5% CR can be the optimum amount to be adopted to use for soil stabilization. Blended PP and CR addition also shows a similar trend. The bridging effect of the fibres could impede the growth of tension cracks. Addition of 4% hydraulic lime modified the highly plastic BC soil to almost non-plastic soil thereby offering sufficient bond strength to the fibres that contributed to the strength of PP reinforced lime cemented soil. 5%CR addition resulted in a strength of about 2.8 times the virgin BC soil. In the lime modified soil, 5%CR addition resulted a strength of about 1.4 and 7 times the strength of lime modified and virgin BC soil respectively. Further, addition of 0.25%PP+5%CR to the lime modified soil shown a strength of about 1.3, 1.9 and 9 times the strength of PP reinforced Lime modified soil, Lime modified and virgin BC soil. It was concluded that 5% CR can be adopted as optimum additive for BC soil improvement provided the other characteristics like Swell-shrink behaviour, durability behaviour, and microstructure etc. also were studied.

References

1. Anil, U., Prasad, S. D., Prasad, D. S. V., Raju, G. P.: A Study on Stabilization of Expansive Soil using Tile Waste and Recron-3S Fibres. SSRG International Journal of Civil Engineering 5(8), 12-16 (2018).
2. ASTM D6276-19: Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization, ASTM International, West Conshohocken, PA (2019). www.astm.org
3. Bell, F. G.: Lime stabilization of clay minerals and soils. Engineering geology 42(4), 223-237 (1996).
4. Cetin, H., Fener, M., Gunaydin, O.: Geotechnical properties of tire-cohesive clayey soil mixtures as a fill material. Engineering geology 88(1-2), 110-120 (2006).
5. Chauhan, M. S., Mittal, S., Mohanty, B.: Performance evaluation of silty sand subgrade reinforced with fly ash and fibre. Geotextiles and geomembranes 26(5), 429-435 (2008).
6. Dash, S. K., Hussain, M.: Lime stabilization of soils: reappraisal. Journal of materials in civil engineering 24(6), 707-714 (2012).
7. Devi, R.: Effect of Inclusion of Coir Fibers of Varying Length on Unconfined Compressive Strength of Expansive Clay. International Research Journal of Engineering and Technology 3(6), 2097-2100 (2016).
8. Dhanya, J. S., Boominathan, A., Banerjee, S.: Response of soil-tyre mixture subjected to cyclic loading. In Proc. of the 16th World Conf. on Earthquake Engineering, Chili (Vol. 1662) (2017).

9. Diamond, S., Kinter, E. B.: Mechanisms of soil-lime stabilization. Highway research record 92, 83-102 (1965).
10. Eid, H. T., Stark, T. D., Evans, W. D., Sherry, P. E.: Municipal solid waste slope failure. I: Waste and foundation soil properties. Journal of Geotechnical and Geoenvironmental Engineering 126(5), 397-407 (2000).
11. Eldin, N. N., Senouci, A. B.: Use of scrap tires in road construction. Journal of Construction Engineering and Management 118(3), 561-576 (1992).
12. Hambirao, G. S., Rakaraddi, P. G.: Soil stabilization using waste shredded rubber tyre chips. IOSR Journal of Mechanical and Civil Engineering 11(1), 20-27 (2014).
13. IS 2720-Part 3-1: Methods of test for soils – Determination of specific gravity, fine grained soils, Bureau of Indian Standards, New Delhi (1980).
14. IS 2720-Part 5: Methods of test for soils – Determination of liquid limit and plastic limit of soils, Bureau of Indian Standards, New Delhi (1985).
15. IS 2720-Part 7: Methods of test for soils – Determination of water content - dry density relation using light compaction, Bureau of Indian Standards, New Delhi (1983).
16. IS 2720-Part 10: Methods of test for soils – Determination of unconfined compressive strength, Bureau of Indian Standards, New Delhi (1991) - RA 1995.
17. IS 2720-Part 40: Methods of test for soils – Determination of free swell index of soils, Bureau of Indian Standards, New Delhi (1977).
18. Jayasree, P. K., Balan, K., Peter, L., Nisha, K. K. Volume change behavior of expansive soil stabilized with coir waste. Journal of materials in Civil Engineering 27(6), 04014195 (2015).
19. Jiang, H., Cai, Y., Liu, J.: Engineering properties of soils reinforced by short discrete polypropylene fiber. Journal of Materials in civil Engineering 22(12), 1315-1322 (2010).
20. Kampala, A., Horpibulsuk, S.: Engineering properties of silty clay stabilized with calcium carbide residue. Journal of Materials in Civil Engineering 25(5), 632-644 (2013).
21. Karnati, V. R., Munaga, T., Gonavaram, K. K., Amitava, B.: Study on Strength and Leaching Behavior of Biogeochemical Cemented Sand. Geomicrobiology Journal 37(7), 670-681 (2020).
22. Kokila, M. L., Bhavithra, G., Hemapriya, V., Iniya, C., Madhunigga, P.: Experimental Investigation on Soil Stabilisation Using Rubber Crumbs on Expansive Soil. World Journal of Research and Review 4(4) (2017).
23. Kumar, A., Walia, B. S., Bajaj, A.: Influence of fly ash, lime, and polyester fibers on compaction and strength properties of expansive soil. Journal of materials in civil engineering 19(3), 242-248 (2007).
24. Madhusudhan, B. R., Boominathan, A., Banerjee, S.: Static and large-strain dynamic properties of sand–rubber tire shred mixtures. Journal of Materials in Civil Engineering 29(10), 04017165 (2017).
25. Malekzadeh, M., Bilsel, H.: Swell and compressibility of fiber reinforced expansive soils. International journal of advanced Technology in civil engineering 1(2), 42-45 (2012).
26. Moghal, A. A. B., Chittoori, B. C., Basha, B. M., Al-Mahbashi, A. M.: Effect of polypropylene fibre reinforcement on the consolidation, swell and shrinkage behaviour of lime-blended expansive soil. International Journal of Geotechnical Engineering 12(5), 462-471 (2018).
27. Muntohar, A. S.: Influence of plastic waste fibers on the strength of lime-rice husk ash stabilized clay soil. Civil Engineering Dimension 11(1), 32-40 (2009).

28. Nakhaei, A., Marandi, S. M., Kermani, S. S., Bagheripour, M. H.: Dynamic properties of granular soils mixed with granulated rubber. Soil dynamics and earthquake engineering 43, 124-132 (2012).
29. Patil, U., Valdes, J. R., Evans, T. M.: Swell mitigation with granulated tire rubber. Journal of materials in civil engineering 23(5), 721-727 (2011).
30. Priya, C. S., Archana, S., Albert, A. B., Deeraj, A. D.: Stabilization of clayey soil using polypropylene fiber. International Research Journal of Engineering and Technology (IRJET) 4(4), 1252-1255 (2017).
31. Priyadarshee, A., Kumar, A., Gupta, D., Pushkarna, P.: Compaction and strength behavior of tire crumbles–fly ash mixed with clay. Journal of Materials in Civil Engineering 30(4), 04018033 (2018).
32. Rogers, C. D. F., GLENDINNING, Roff, T. E. J.: Lime modification of clay soils for construction expediency. Proceedings of the Institution of Civil Engineers-Geotechnical Engineering 125(4), 242-249 (1997).
33. RU, A. K., Shafin, M. M., Madhavan, R., Rajkumar, R.: Waste Plastic Fiber Reinforced Soil. Thesis submitted to Velammal Engineering College, Chennai (2015).
34. Suluguru, A. K.: Experimental investigations on potential of brick-based building-derived materials for geotechnical applications. Innovative Infrastructure Solutions 5(85), 1-11 (2020).
35. Tang, C., Shi, B., Gao, W., Chen, F., Cai, Y.: Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. Geotextiles and Geomembranes 25(3), 194-202 (2007).
36. Tang, C. S., Shi, B., Cui, Y. J., Liu, C., Gu, K.: Desiccation cracking behavior of polypropylene fiber–reinforced clayey soil. Canadian Geotechnical Journal 49(9), 1088-1101 (2012).
37. Vasudevan, R., Sekar, A. R. C., Sundarakannan, B., Velkennedy, R.: A technique to dispose waste plastics in an ecofriendly way–Application in construction of flexible pavements. Construction and Building Materials 28(1), 311-320 (2012).
38. Vinod, J. S., Sheikh, M. N., Mashiri, S.: Cyclic behaviour of scrap-tyre soil mixtures. In Frontiers in Geotechnical Engineering, pp. 303-311. Springer, Singapore (2019).
39. Yadav, J. S., Tiwari, S. K.: Effect of inclusion of crumb rubber on the unconfined compressive strength and wet-dry durability of cement stabilized clayey soil. Journal of building materials and structures 3(2), 68-84 (2016).
40. Youwai, S., Bergado, D. T.: Strength and deformation characteristics of shredded rubber tire sand mixtures. Canadian geotechnical journal 40(2), 254-264 (2003).