Effect of Polypropylene Fibre and Curing Period on Unconfined Compressive Strength of Cemented-Black Cotton Soil

Ravi Gupta, P.K. Jain, Rakesh Kumar

Abstract*: This paper discussed the effect of polypropylene fibre and curing period on the unconfined compressive strength (UCS) of cemented-black cotton soil. Various combinations of polypropylene fibres and cement have been taken and the UCS values of the treated black cotton soil specimens were determined after 3, 7 and 28days of curing. The study divulged that the mixing of polypropylene fibre increases UCS of cemented-black cotton soil. The rise in strength depends on the curing period. The 28days strength is 50 to 90% more than the corresponding 3days strength. The maximum enhancement of UCS from 969 to 2431kPa is achieved by adding 1% polypropylene fibre in cemented-black cotton soil having 15% cement after a curing period of 28days. The UCS of cemented-soil with 5% cement content, (Cc) and 1% polypropylene fibre is 781kPa which corresponds to the UCS of cemented-black cotton soil with 12% cement alone after a curing period of 28days. Thus, polypropylene fibre might be an economical admixture to enhance the performance of soil-cement column stabilised black cotton soil.

Keywords*: Black cotton soil, curing period, polypropylene fibre, soil mixing technique, soil-cement column, unconfined compressive strength.

I. INTRODUCTION

Black cotton soil is among the most prevalent soils found in south Asia, middle Africa and other tropical areas. The soil is recognised for its low shear strength, high compressibility and excessive volume increase due to ingress of water. The construction of structures on or with this soil requires the consideration of stability and strength. The soil is considered as highly problematic for both buildings and road structures and behaves as a soft soil in wet condition. In the last decades, researchers reported several solutions for soft soils. These include the use of vertical drain, prefabricated vertical drain, preloading, vacuum preloading, grouting, concrete pile and granular pile. However, use of granular piles in strengthening of black cotton soil is reported by [32].

Another technique which gained popularity in strengthening the weak, soft soils is the deep soil mixing method. It is an advanced ground strengthening technique; in which cement (or other binder material) in powdered or slurry form (i.e., dry mixing or wet mixing) mix with the in-situ soil to construct in-place soil-cement columns that reduce the compressibility and improves the strength of the soft ground [1]. The technique requires injecting cement through injection tubing and the mixing is achieved through a specialized auger with the mixing paddle. Mixing of the soil with cement, initially destroys the natural bonds between the clay matrices, meanwhile new bonds are created due to the chemical reaction of the soil particles with cement. The primary factors that govern the behaviour of cemented-soil are identified as the nature of the soil, cement content, efficiency of mixing, compacting water content, dry density and the curing period of the compacted mix [23]. Some other factors like the curing temperature, humidity and stresses during the treatment period, also affect the development of strength in cement mixed soil. Usually, the longer the curing period, higher the strength developed irrespective of the soil types, due to the pozzolanic reaction [26,22,16,40]. In the field, the soil-cement columns by deep soil mixing technique are installed in a triangular, square or rectangular grid pattern. In general, the column diameter ranges from 0.5 to 1.75m, centre to centre spaced between 1 and 1.5m and the height varies from 10 to 30m [12]. The UCS of the cement stabilized soil was observed in the range from 2 to 4MPa with a Cc of 200 to 300kg/m3 [35]. This method is economical and requires less time when used for the treatment of soil in large areas [34].

A few field examples of the deep soil mixing technique are: soil stabilisation of Bagna-Bangkapong highway in Thailand [14], foundation support of a multilevel parking in Allentown, Pennsylvania [19], cut and cover tunnel-Pennsylvania [13], foundation support of dome at port of Stockton, California [24], excavation support structure of the museum of fine arts, Boston [11], stabilisation of weak soil of SR 83/US 331 corridor in Florida [41].

Deep soil mixing technique applies to a large range of soils such as clays, silty clays, silts, sandy silts, sands, peat and organic clays [18,2,12,25]. But, in the case of organic soils, the degree of improvement is less likely to be of the same order as that for inorganic soils at practical dosages (4 to 18%) of the stabilizer. Soils with low pH values exhibited low strength gains even though there is a tendency to rise in strength with the amount of stabiliser [33]. The black cotton soil retains high water during the rainy season and its water content could be near to its liquid limit value, and as a result the soil strength reduces drastically.

Revised Manuscript Received on October 20, 2019.

* Correspondence Author

Ravi Gupta*, Research Scholar, Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal, India. Email: ravigupta385@gmail.com

Dr. P.K.Jain, Professor, Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal, India.. Email: pkjain10@rediffmail.com

Dr. Rakesh Kumar, Associate Professor, Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal, India. Email: rakesh20777@gmail.com

The ground improvement in such soils using deep soil mixing technique with cement, needs to be explored as it may result in a technically viable and economical solution to tackle the problems associated with such soils.

Despite of the benefits of cement usage for soil improvement, its adverse effect on environment also needs to be considered. The cement manufacturing plants release carbon-di-oxide (CO2) [15], Nitrogen-oxides (NOx) [39] and particulate emission in the air and therefore, any effort to reduce the consumption of cement is a welcome step towards sustainable infrastructure. One such additive that can reduce the use of cement could be the polypropylene fibre.

Polypropylene fibre is a petroleum by-product and transformed from monomer propylene. It is widely used as an admixture with cement concrete to improve its workability, mechanical strength, stiffness and durability [42,31]. Nowadays it is also mixed with soils, which improves its mechanical properties [38,36,17,8,5,28] and also improves the strength of cemented-soil [37,20,4,27,10,30,6,7]. Hadi [28] observed that by mixing 4% polypropylene fibre with brown clay, the friction angle of the soil increased from 12° to 23°, the swell percent decreased from 7.54% to 1.56%, the California Bearing Ratio (CBR) value improved from 4 to 10% and the UCS increased from 165 to 490kPa. The underlying mechanism is that the stress is transmitted from the soil particles to the fibres, thus mobilising their tensile strength that imparts resistance to the soil, thereby leading to an enhancement in load carrying capacity of the cemented-soil. Khattak and Alrashidi [27] reported the effect of polypropylene fibre on cemented-soils. They found that by mixing 0.15% polypropylene fibre by weight of dry soil, the UCS of cement-stabilised soil enhanced by 45%. Consoli et al. [30] also observed that polypropylene fibre inclusion causes a further rise in the UCS of cement stabilised silty sand. It was noticed that the inclusion of polypropylene fibre in cemented-soil improves its tensile, compressive strength and reduces brittleness. Thus, polypropylene fibre can be an economical and environmental viable additive to enhance the efficiency of soil-cement column reinforced soils.

From the above discussion, it may be concluded that the technique of deep soil mixing using cement and polypropylene fibre in strengthening the black cotton soil is an unexplored research area. To address this research gap, the effect of polypropylene fibre and curing period on the UCS of cemented-black cotton soil is studied in the present work. The black cotton soil during rainy season retains large amount of moisture, hence the moisture content in the present work is kept high at 35%. Three polypropylene fibre contents (Fc) were used 0.3, 0.6, and 1% by weight of the dry soil, whereas the cement content (Cc) in the mix was kept as 5, 10 and 15% by weight of the dry soil. The unconfined compression test was performed after 3, 7 and 28days of curing.

II. MATERIAL PROPERTIES

The materials used in this research work are the black cotton soil, cement and the polypropylene fibre. The black cotton soil used was collected from the college campus of Maulana Azad National Institute of Technology (MANIT), Bhopal. The basic properties of the black cotton soil are listed in Table- I.

Table- I: Properties of black cotton soil

Properties	Value
Clay content Silt content Sand content	74.6% 25.4% Nil
Specific gravity	2.74
Consistency limits Liquid limit Plastic limit Plasticity index	 55% 27% 28%
Differential free swell index	55%
Modified proctor test Maximum dry density (MDD) Optimum water content (OMC)	 15.40 kN/m3 24.50
IS soil classification	CH

The cement used in this study is ordinary Portland cement (OPC) of Grade 43 manufactured by JK Lakshmi Cement Limited. The physical and chemical properties of the cement are listed in Tables- II and III.

Table- II: Physical properties of the cement (source: manufacturer datasheet)

Properties↓	Values →	Standard	Test results
Fineness (m^2/kg)		≯225	279
Soundness Le Chatelier's Method(mm) max		≮10	1
Setting Time (minutes)	*Initial*	≯30	135
	Final	≮600	275
Compressive Strength (MPa)	*3days*	≯23	33
	7days	≯33	41
	28days	≯43	50

Table- III: Chemical properties of the cement (source: manufacturer datasheet)

Composition	OPC
Calcium Oxide, CaO	65%
Aluminium Oxide, Al_2O_3	5%
Silicon Oxide, SiO_2	20%
Sodium Oxide, Na_2O	0.5%
Ferric Oxide, Fe_2O_3	1.7%
Magnesium Oxide, MgO	4%
Potassium Oxide, K_2O	0.8%
Sulphur Trioxide, SO_3	3%
Specific Gravity, Gs	3.15

The polypropylene fibre used in the experiments is obtained from Reliance Industries Limited. The properties of polypropylene fibre are listed in Table- IV.

Table- IV: Properties of polypropylene fibre (source: manufacturer datasheet)

Properties	Value
Length of fibre	6mm
Diameter of fibre	30 µm
Specific surface	140 m^2/kg
Unit weight	8.5 kN/m^3
Tensile strength	270 MPa

Properties	Value
Length of fibre	6mm
Young's modulus	3700 MPa

Fig. 1. Polypropylene fibres used in the study.

III. METHODOLOGY

The soil collected from the field was cleaned and made free from foreign materials. The clean soil was dried, pulverized and sieved through 75-micron sieve to remove the coarser fraction. The cement content (Cc) used in the study was selected as 5, 10 and 15%. The selected Cc is within the range suggested by past research, which is between 4 and 18% for soil cement-column reinforced clays [38,16,40]. The polypropylene fibre content (Fc) chosen were 0.3, 0.6, and 1%, which is consistent with past research in which less than 1.5% of fibre was used in soil improvement studies [37,20,4,27,10,30,29,6].

The soil containing desired amount of water and cement, or water, cement and fibres was compacted in the standard compaction mould. The specimens for unconfined compression test were obtained from the mould. These specimens were kept in a humid curing chamber at a relative humidity of 80-85% and constant temperature of 25 ± 2°C for different curing periods. The UCS tests were conducted for the following combinations of soil, cement, fibres and curing periods are given in Table- V.

The unconfined compression test was performed using a motorised strain control mechanism as per IS 2720 (Part 10)-1991 [9]. The strain rate of 0.5 mm/min was applied and the soil resistance was noted through a calibrated proving ring. The test was conducted till the specimen failed (Fig.2).

Fig. 2. UCS samples after the test.

Table- V: Summary of UCS test conducted.

Soil Specimen Type	Test Variables			Number of UCS Samples Tested
	Cement Content (Cc)	*Polypropylene Fibre Content (Fc)*	*Curing Period*	
Black cotton soil at 35% water content	-	-	-	1
Black cotton soil mixed with cement	5,10 and 15%	-	3,7 and 28days	9
Black cotton soil mixed with cement and polypropylene fibres	5,10 and 15%	0.3, 0.6 and 1%	3,7 and 28days	27
Total Number of UCS Samples Tested				37

IV. RESULTS AND DISCUSSION

A. Effect of mixing cement and curing period on UCS of the black cotton soil

The UCS of the black cotton soil at OMC and water content of 35% were determined and found to be 76.45 and 18.80kPa respectively (Fig.3).

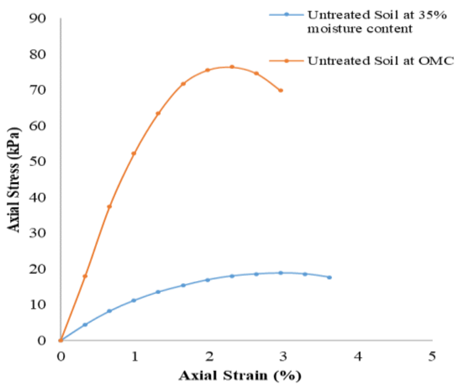

Fig. 3. Axial stress-axial strain curve for untreated black cotton soil at OMC and 35% water content.

The effect of mixing cement with black cotton soil after curing of 3days is presented in Fig.4a. The UCS values for 5, 10 and 15% cement mixed soil with the initial moisture content of 35% are 173.85, 438.11 and 575.15kPa respectively. Similarly, the corresponding values after 7days of curing are 241.29, 530.60 and 649.21kPa (Fig.4b) and after 28days of curing are 337.81, 640.30 and 969.37kPa for (Fig.4c) respectively.

The effect of curing at different Cc is presented through Fig.5. It should be observed that with an increment in the Cc and the curing period, the UCS of the black cotton soil increases significantly. Similar trend is reported by [26,25,22,16,28,40].

In case of cement mixed black cotton soil, hydration of cement is a time dependent process, i.e., increasing the curing period is reflected in the increase of the soil strength. When dry cement is mixed with soft soil, it reacts with the water within the soil and a chemical process starts. Consequently, Calcium-Silicate-Hydrate [C3S2H4 (C-S-H)] gel is formed. The C-S-H gel binds the soil particles together, filling voids and becoming stronger and denser with time [21,3,36,17,8,5].

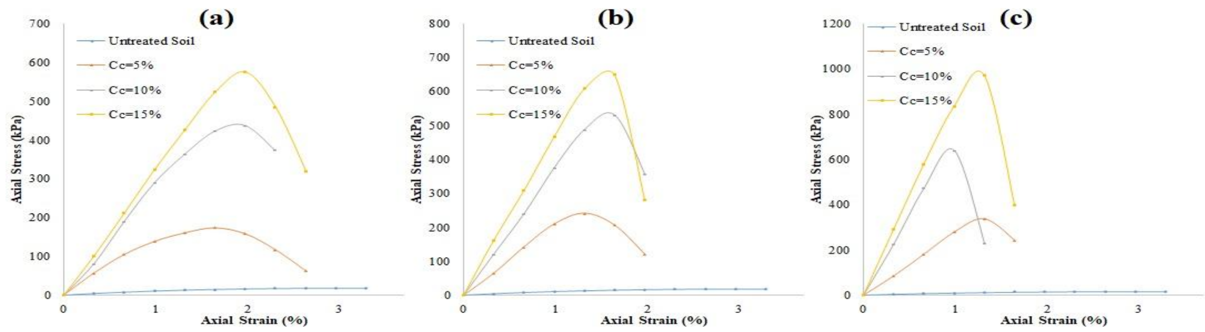

Fig. 4. Axial stress-axial strain curve for cement mixed black cotton soil at curing period of (a) 3days (b) 7days and (c) 28days.

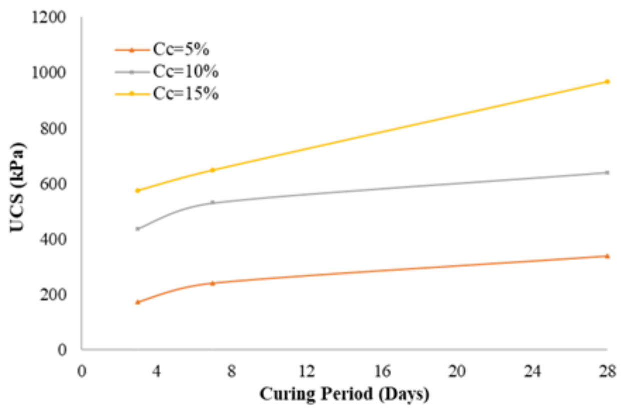

Fig. 5. Variation of UCS with curing period (in days) of cement mixed black cotton soil.

B. Effect of mixing polypropylene fibre and curing period on UCS of cemented-black cotton soil

Figs. 6a, 6b and 6c shows the effect of polypropylene fibres in cement mix black cotton soil after a curing period of 3days. The UCS of 5% cement mixed black cotton soil has increased from 173.85kPa to 281.74kPa at 0.3% Fc and has further increased to 325.49kPa at 0.6% Fc and 409.64kPa at 1% Fc (Fig.6a). Similar trend is observed for 10 and 15% cement mixed black cotton soil (Fig.6b and 6c). The maximum UCS of 1329.28kPa is obtained at 1% Fc and 15% Cc.

The results of the UCS tests conducted after a curing period of 7 and 28days are compiled along with that of 3days are presented in Table- VI.

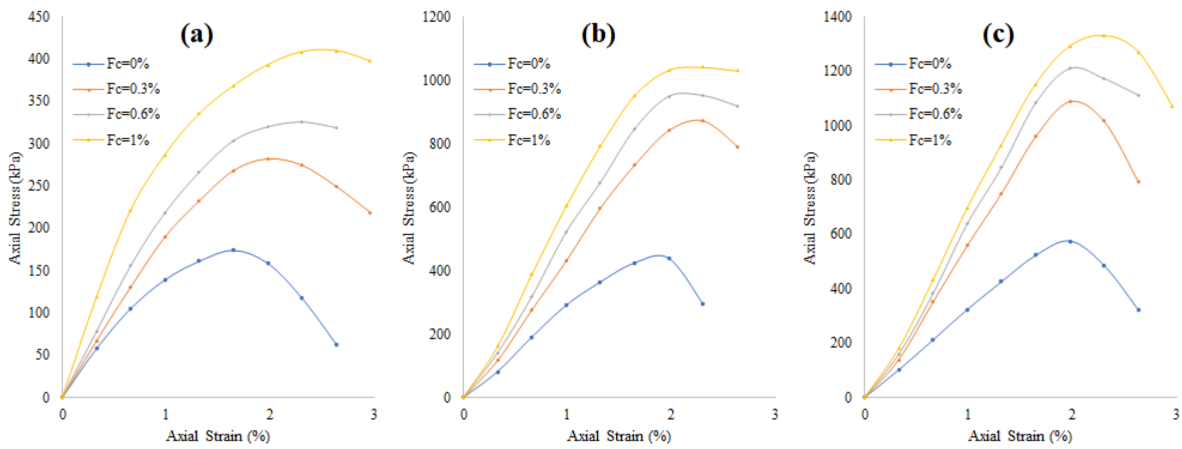

Fig. 6. Axial stress-axial strain curve for polypropylene fibres mixed cemented-black cotton soil: Cc (a) 5%, (b) 10%, (c) 15% at curing period of 3days.

Table- VI: UCS values of polypropylene fibres mixed cemented-black cotton soil.

Cement Content (Cc)	Polypropylene Fibre Content (Fc)	UCS (kPa)		
		3 Days	*7 Days*	*28 Days*
5%	0%	174	241	338
	0.3%	282	519	573
	0.6%	325	561	640
	1%	410	641	781
10%	0%	438	531	640
	0.3%	871	1035	1510
	0.6%	951	1110	1632
	1%	1040	1172	1909
15%	0%	575	649	969
	0.3%	1090	1339	1670
	0.6%	1210	1398	2296
	1%	1329	1555	2431

The rate of enhancement in UCS value with the curing period can be seen in Fig.7. It may be noted that UCS increases relatively fast from 3days to 7days and thereafter a gradual increase is observed.

For polypropylene fibre-reinforced cemented-soil, the discrete fibres create a 3D network, wherein the particles of soil links with each other to create a coherent unit, that restricts the motion of the soil particles. Shearing resistance is developed along the fibre surface as a consequence of interlocking, bond and friction between the surface of fibres and soil particles (Fig.8). This resistance prevents the fibre from sliding out of the soil, and hence increases the tensile capacity of the fibre mixed cemented-soil [10,6].

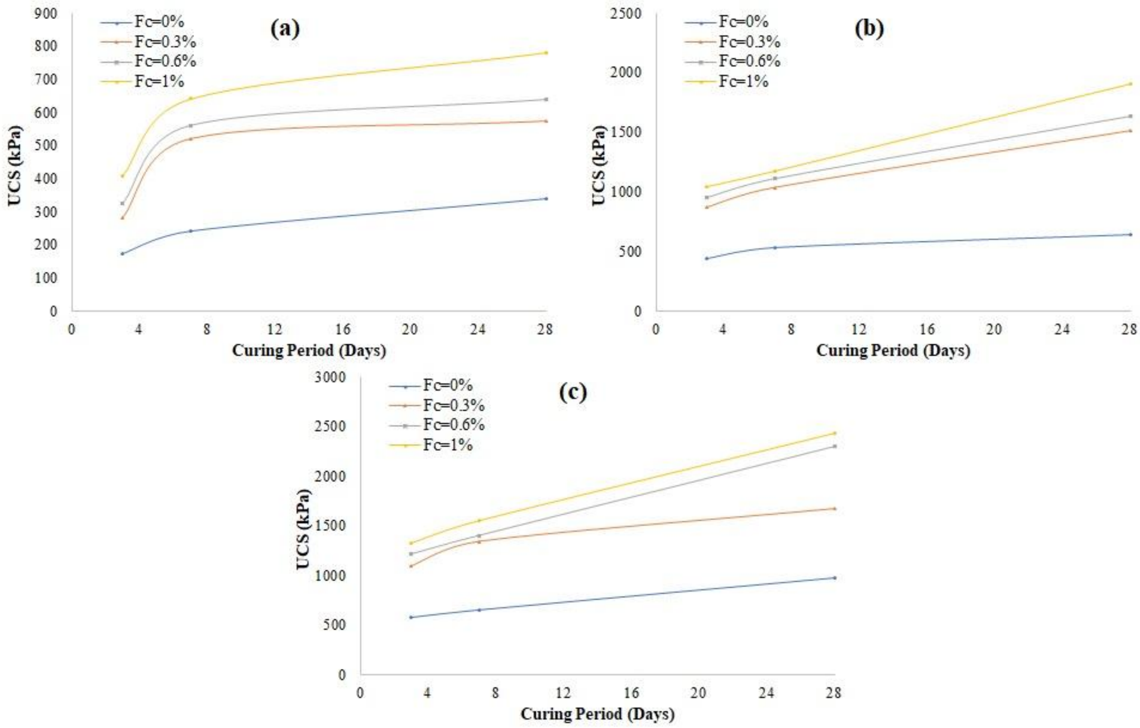

Fig. 7. Variation in UCS with curing period (in days) of polypropylene fibres mixed cemented-black cotton soil: Cc (a) 5%, (b) 10%, (c) 15%.

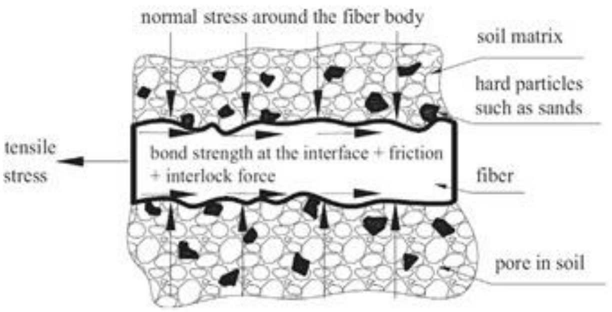

Fig. 8. Mechanism of interaction between polypropylene fibre and soil particles (Tang et al., 2007).

When the polypropylene fibre admixed cemented-soil is loaded, the polypropylene fibres restrict tension cracks in the soil and limits the deformation, that also explains the ductile behaviour of polypropylene fibre mixed cemented-soil. Many studies have explained that the effectiveness of polypropylene fibre mixed soil depends on two primary factors, 1) polypropylene fibre properties (i.e., material, content, length and surface roughness) and 2) the surface shearing resistance force that depends mainly on the particle size distribution and the soil cohesion [37,4,10]. Consequently, the efficiency of polypropylene fibre mixed cemented-soil with high Cc is much greater than cemented-soil with low Cc. Increasing the Cc will improve the mobilized cohesion around polypropylene fibre surface and the soil particles, enhances the polypropylene fibres effectiveness and improves the soil strength.

C. Feasibility study of mixing polypropylene fibre in cemented-black cotton soil

Fig.9 shows that the UCS of cemented-soil with 5% Cc and 1% Fc is 781kPa which corresponds to the UCS of cemented-black cotton soil with 12% cement alone after a curing period of 28days. Thus 0.1% polypropylene fibre replaces about 7% cement. Though the results of this study reinforce the beneficial effect of polypropylene fibre on improving the strength of cemented-black cotton soil; its environmental and economic impact should also be evaluated thoroughly.

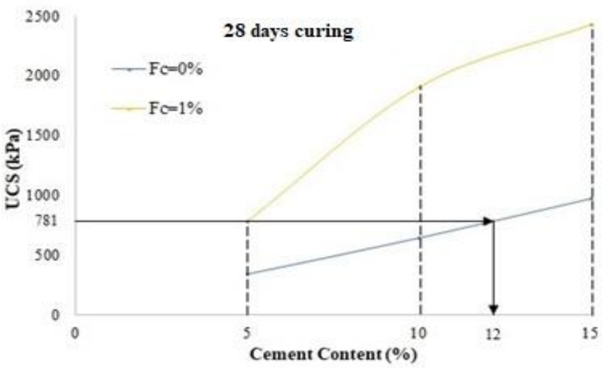

Fig. 9. Comparative performance of cemented black cotton soil and polypropylene fibre mixed cemented black cotton soil.

V. CONCLUSIONS

Present research is conducted on black cotton soil in its soft state at moisture content as high as 35%, giving UCS of 18.8kPa. It confirms that mixing of cement enhances the black cotton soil strength. For cemented soil, the chemical reaction is a time function i.e., increasing the curing period contributes to an increase in soil strength. The UCS of the cemented black cotton soil is observed to increase with the amount of cement and curing period. The 28days UCS of 15% cement mixed soil is found to be 969kPa, which is significantly larger than the corresponding value of 575 and 649kPa for 3 and 7days curing.

In case of polypropylene fibre treated cemented-soil, enhanced fibre efficiency is observed at higher Cc. The strength of the black cotton soil mixed with 5% cement and 1% fibre is found more than twice compared to the corresponding value for 5% cement mixed soil alone. Similar effect of polypropylene fibre mixing was observed for 10 and 15% cement mixed soil. The 28days UCS of cemented-soil with fibre is significantly larger than the corresponding value for 3 and 7day curing. The enhancement in strength of soil with the period of curing owing to increase in the cement strength with curing time that enhances the friction on the surface of polypropylene fibre with the adjacent soil media, thus raising the efficiency of the polypropylene fibres.

The UCS of the soil with 5% cement and 1% polypropylene fibre is found 781kPa; which by linear interpolation corresponds to cemented-black cotton soil with 12% cement alone after a curing period of 28days. Thus, polypropylene fibre could be an economical additive to replace the cement partially, with improved performance of soil-cement column stabilised black cotton soil.

The study encourages further research to investigate the sustainability about the use of polypropylene fibre admixed soil-cement column to strengthen the black cotton soil in the field.

REFERENCES

1. A. Dehghanbanadaki, K. Ahmad, N. Ali, M. Khari, P. Alimohammadi, and N. Latifi, "Stabilization of soft soils with deep mixed soil columns - general perspective." Electron. J. Geotech. Eng., vol. 18, 2013, pp. 295–306.
2. A. Porbaha, "State of the art in deep mixing technology: part I. Basic concepts and overview." Proc. Inst. Civ. Eng. Ground Improv., vol. 2(2), 1998, pp. 81-92.
3. A. Sreekrishnavilasam, S. Rahardja, R. Kmetz, and M. Santagata, "Soil treatment using fresh and landfilled cement kiln dust." Constr. Build. Mater., vol. 21(2), 2007, pp. 318-327.
4. A. Tagnit-Hamou, Y. Vanhove, and N. Petrov, "Microstructural analysis of the bond mechanism between polyolefin fibers and cement pastes." Cem. Concr. Res., vol. 35(2), 2005, pp. 364–370.
5. A.A. Amadi, "Enhancing durability of quarry fines modified black cotton soil subgrade with cement kiln dust stabilization." Transp. Geotech., vol. 1(1), 2014, pp. 55-61.
6. A.A. Correia, P.J.V. Oliveira, and D.G. Custódio, "Effect of polypropylene fibres on the compressive and tensile strength of a soft soil, artificially stabilised with binders." Geotext. Geomembr., vol. 43(2), 2015, pp. 97-106.
7. A.A.B. Moghal, B. Chittoori, B.M. Basha, and M.A. Al-Shamrani, "Target reliability approach to study the effect of fiber reinforcement on UCS behavior of lime treated semi-arid soil." J. Mater. Civ. Eng., vol. 29(6), 2017, pp. 1-15.
8. A.B. Salahudeen, A.O. Eberemu, and K.J. Osinubi, "Assessment of cement kiln dust-treated expansive soil for the construction of flexible pavements." Geotech. Geol. Eng., vol. 32(4), 2014, pp. 923-931.
9. Bureau of Indian Standards (BIS), "Methods of test for soils; Determination of Unconfined Compressive Strength" IS 2720-Part 10, 1991, New Delhi.
10. C. Tang, B. Shi, W. Gao, F. Chen, and Y. Cai, "Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil." Geotext. Geomembr., vol. 25(3), 2007, pp. 194-202.
11. D. Weatherby, and D. Zywicki, "Deep soil mixed wall and jet grouting for an excavation retention system at the museum of fine arts Boston." Proc. 4th Int. Conf. Grouting and Deep Mixing, New Orleans, Louisiana, 2012, pp. 379-388.
12. D.A. Bruce, "Practitioner's guide to the deep mixing method." Proc. Inst. Civ. Eng. Ground Improv., vol. 5(3), 2001, pp. 95–100.
13. D.R. McMahon, P. Maltese, K.B. Andromolos, and K.L. Fishman, "A DSM wall for excavation support." Found.Ground Improv., 2001, pp. 670-684.
14. D.T. Bergado, T. Ruenkrairergsa, Y. Taesiri, and A.S. Balasubramaniam, "Deep soil mixing used to reduce embankment settlement." Proc. Inst. Civ. Eng. Ground Improv., vol. 3(4), 1999, pp. 145-162.
15. E. Worrell, L. Price, N. Martin, C. Hendriks, and L.O. Meida, "Carbon dioxide emissions from the global cement industry." Annu. Rev. Energy Env., vol. 26(1), 2001, pp. 303-329.
16. F. Szymkiewicz, A. Guimond-Barrett, A.L. Kouby, and P. Reiffsteck, "Influence of grain size distribution and cement content on the strength and aging of treated sandy soils." Eur. J. Environ. Civ. Eng., vol. 16(7), 2012, pp. 882-902.
17. F.O.P. Oriola, and G. Moses, "Compacted black cotton soil treated with cement kiln dust as hydraulic barrier material." Am. J. Sci. Ind. Res., vol. 2(4), 2011, pp. 521-530.
18. H. Ahnberg, C. Ljungkrantz, and L. Holmqvist, "Deep stabilization of different types of soft soils." Proc. 11th ECSMFE, vol. 7, 1995, pp. 167-172.
19. J. Cavey, L.F. Johnsen, and J. DiStas, "Deep soil mixing for foundation support of a parking garage." Proc. GeoSupport Conf., Orlando, Florida, 2004, pp. 955-964.
20. J.D. Frost, and J. Han, "Behavior of interfaces between fiber-reinforced polymers and sands." J. Geotech. Geoenviron. Eng., vol. 125(8), 1999, pp. 633–640.
21. K.J. Osinubi, "Stabilization of tropical black clay with cement and pulverized coal bottom ash admixture." Adv. Geotech. Advances in Unsaturated Geotechnics, vol. 99, 2000, pp. 289-302
22. K.J. Osinubi, M.A. Oyelakin, and A.O. Eberemu, "Improvement of black cotton soil with ordinary portland cement -locust bean waste ash blend." Electron. J. Geotech. Eng., vol. 16, 2011, pp. 619-627.
23. K.K. Askarani, and M.S. Pakbaz, "Drained shear strength of over-consolidated compacted soil-cement." J. Mater. Civ. Eng., vol. 28(5), 2016.
24. L. Shao, and K. Ivanetich, "Heavy structures supported by soil-cement columns." Proc. GeoShanghai Int. Conf. Ground Improv. Geosynthetics, Shanghai, 2010, pp. 125–130.
25. L.S. Wong, R. Hashim, and F.H. Ali, "Strength and Permeability of Stabilised Peat Soil." J. Appl. Sci., vol. 8(17), 2008, pp. 1-5.
26. M. Bouassida, and A. Porbaha, "Ultimate bearing capacity of soft clays reinforced by a group of columns-application to a deep mixing technique." Soils Found., vol. 44(3), 2004, pp. 91-101.
27. M.J. Khattak, and M. Alrashidi, "Durability and mechanistic characteristics of fiber reinforced soil-cement mixtures." Int. J. Pavement Eng., vol. 7, 2006, pp. 53-62.
28. N.A.R.A. Hadi, "Utilization of polymer fibers and crushed limestone sand or stabilization of expansive clays in Amman area." Int. J. Geotech. Eng., vol. 10(5), 2016, pp. 428-434.
29. N.C. Consoli, F. Zortea, M. Souza, and L. Festugato, "Studies on the dosage of fiber reinforced cemented soils." J. Mater. Civ. Eng., vol. 23(12), 2011, pp. 1624-1632.
30. N.C. Consoli, M.A.A. Bassani, and L. Festugato, "Effect of fiber-reinforcement on the strength of cemented soils." Geotext. Geomembr., vol. 28(4), 2010, pp. 344-351.
31. P. Balaguru, and A. Khajuria, "Properties of polymeric fiber-reinforced concrete." Transp. Res. Rec., vol. 1532, 1996, pp. 27–35.
32. R. Kumar, and P.K. Jain, "Prospect of using granular piles for improvement of expansive soil." Int. J. Adv. Eng. Technol., vol. 3(3), 2012, pp. 79-84.
33. R.M. Babasaki, T. Terashi, A. Suzuki, M. Maekaea, E. Kawamura, and E. Fukazawa, "JGS TC report: factors influencing the strength of improved soil." Proc. 2nd Int. Conf. Ground Improv. Geosyst., Tokyo, vol. 2, 1996, pp. 913-918.

34. S. Hebib, and E.R. Farrell, "Some experiences on the stabilization of Irish peats." Can. Geotech. J., vol. 40(1), 2003, pp. 107–120.
35. S. Hibino, "Monitoring of subsidence of building on ground improved by deep mixing method." Proc. 2nd Int. Conf. Ground Improv. Geosyst., Tokyo, vol. 1, 1996, pp. 595-601.
36. S. Peethamparan, J. Olek, and J. Lovell, "Influence of chemical and physical characteristics of cement kiln dusts (CKDs) on their hydration behavior and potential suitability for soil stabilization." Cem. Concr. Res., vol. 38(6), 2008, pp. 803-815.
37. S.P. Shah, "Do fibers increase the tensile strength of cement-based matrixes?" ACI Mater. J., vol. 88(6), 1991, pp. 595–602.
38. T. Okumura, "Deep mixing method of Japan." Proc. 2nd Int. Conf. Ground Improv. Geosyst., Tokyo, vol. 2, 1996, pp. 879–887.
39. T.W. Bremner, "Environmental aspects of concrete: problems and solutions." Proc. 1st All- Russian Conf. Concr. Reinf. Concr., Moscow, 2001, pp. 232-246.
40. V.N. Pham, B. Turner, J. Huang, and R. Kelly, "Experimental study on the durability of soil-cement columns in coastal areas." Proc. 19th SEAGC & 2nd AGSSEA Conf., Kuala Lumpur, 2016.
41. W. Schmutzler, G. Mullins, and M. Bertoni, "Soil mixing for the SR-83 project in Florida." Proc. 5th Int. Conf. Grouting, 2017, pp. 434-444.
42. Z. Bayasi, and J. Zeng, "Properties of polypropylene fibre reinforced concrete." ACI Mater. J., vol. 90(6), 1993, pp. 605–610.

AUTHORS PROFILE

Mr. Ravi Gupta is a Research Scholar in Civil Engineering Department in Maulana Azad National Institute of Technology, Bhopal, India. He received his Bachelor's Degree in Civil Engineering from RGPV University, Bhopal, India. He obtained his Master's Degree in Geotechnical Engineering from Maulana Azad National Institute of Technology, Bhopal, India. His main research interest includes advanced soil stabilisation techniques, low cost soil strengthening admixtures, deep mixing method, stone column and numerical modelling. He has published various research papers in reputed National/International Journal. He is expert in soil stabilisation techniques, Distribution Network design, Optimisation and Modelling treatment plant design, PLAXIS, AutoCAD, SigmaPlot, STAAD.Pro. He has participated in various Faculty Development Programme / Short Term Training Programme / Workshop / Conferences / Seminars