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Performance of fly ash stabilized clay reinforced with human hair fiber

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Abstract. Industrialization and urbanization are the two phenomena that are going relentless all over the world. The consequence of this economic success has been a massive increase in waste on one hand and increasing demand for suitable sites for construction on the other. Owing to the surplus raw materials and energy requirement needed for manufacturing synthetic fibers, applications of waste fibers for reinforcing soils evidenced to offer economic and environmental benefits. The main objective of the proposed work is to explore the possibilities of improving the strength of soil using fly ash waste as an admixture and Human Hair Fiber (HHF) as reinforcement such that they can be used for construction of embankments and land reclamation projects. The effect of fiber content on soil – fly ash mixture was observed through a series of laboratory tests such as compaction tests, CBR and unconfined compression tests. From the stress - strain curves, it was observed that the UCC strength for the optimised soil – flyash mixture reinforced with 0.75% human hair fibers is nearly 2.85 times higher than that of the untreated soil. Further, it has been noticed that there is about 7.73 times increase in CBR for the reinforced soil compared to untreated soil. This drastic increase in strength may be due to the fact that HHF offer more pull-out resistance which makes the fibers act like a bridge to prevent further cracking and thereby it improves the toughness which in turn prevent the brittle failure of soil-flyash specimen. Hence, the test results reveal that the inclusion of randomly distributed HHF in soil significantly improves the engineering properties of soil and can be effectively utilized in pavements. SEM analysis explained the change of microstructures and the formation of hydration products that offered increase in strength and it was found to be in accordance with strength tests.

Keywords: clay; ground improvement; fly ash; randomly distributed fiber; soil reinforcement

1. Introduction

Structures built on expansive clays are likely to be damaged due to the strains caused in them following alternate swelling and shrinkage. Ground improvement methods are used increasingly for new projects to allow utilization of such sites with poor subsurface conditions and to allow design and construction of needed projects despite poor subsurface conditions which formerly would have rendered the project economically unjustifiable or technically not feasible. Randomly distributed fiber reinforced soil-termed as RDFS is among the latest ground improvement

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techniques in which fibers of desired type and quantity are added in soil, mixed randomly and laid in the position after compaction. At the same time, coal based power plant requires coal of high calorific value to generate optimum heat consequently to generate electricity and in this process a by-product which is also hazardous waste, fly-ash or coal ash is produced. Present generation of fly ash from coal based thermal power plants in India is 131 MT/year and it is expected to increase to 300-400 MT/year by 2016-17 (Source: CEA annual report on fly ash generation 2010-2011). Therefore, the problems related with their safe management and disposal has become a major challenge to environmentalists and scientists. Hence fly ash can be effectively used for stabilizing the expansive soil on one hand and wastes can be effectively utilized on the other hand.

In order to improve the problematic soil on one side and effectively utilize the fly ash (FA) and Human hair fiber (HHF) on the other side, an integrated approach has been carried out in this research to study the effect of fly ash waste as an admixture and HHF as reinforcement on the California Bearing Ratio (CBR), Unconfined compression (UCC) and Swelling characteristics of expansive soils.

Prabakar *et al*. (2004) presented that introduction of fly ash in soil reduces the swelling in the soil due to non-expansive characteristics of fly ash and the particle size. Phanikumar and Sharma (2004) concluded that the undrained shear strength of expansive soil blended with fly ash increases with the increase in the ash content. Edil *et al*. (2006) indicated the effectiveness of fly ash on the CBR and resilient modulus of soft fine grained subgrade soil. Akhtar *et al*. (2008) studied the influence of randomly oriented hair fiber and lime on the CBR value of flyash and observed that the CBR value increases nearly 3 times that of plain fly ash when it is mixed with 1.5% lime and 2% hair fibers. Based on the research results, Hasan (2012) presented that liquid limit decreased with increasing fly ash content, and the plastic limit decreased with increasing fly ash content, thereby resulting in a decrease in plasticity index. In the recent years, several researchers are trying to use different types of fibers as reinforcing materials, such as natural fibers, glass fibers, plastic fibers, polypropylene and polyester fibers. Experimental results reported by various researchers (Shewbridge and Sitar 1989, Maher and Gray 1990, Maher and Ho 1994, Sivakumar Babu and Vasudevan 2008, Sivakumar Babu and Chouksey 2010) showed that the fiber reinforced soil is a potential composite material which can be advantageously employed in improving the structural behavior of soils. Jiang *et al*. (2010) studied the effect of varying fiber content and fiber length on the strength of the fiber reinforced soil and observed that fibers of length less than 15 mm contribute to better reinforcement effect in strength than do longer fibers greater than 15 mm. Pillai and Ramanathan (2012) conducted strength tests on soil reinforced with 0.5%, 1%, 1.5%, 2%, 2.5% human hair fibers and inferred that it could be effectively used in cohesive soils. Pradhan *et al*. (2012) noticed that the optimum polypropylene fiber content for achieving maximum strength is 0.4%-0.8% of the weight of oven-dried soil for fiber aspect ratio of 100. Mali and Singh (2014) studied the stress strain behavior of silty soil by incorporating coir fibres into it and observed that the deviator stress at failure increased up to 3.5 times over plain soil due to the fiber inclusion.

2. Materials used

In order to evaluate the possibilities of large scale utilization of fly ash for the stabilization of soils, natural soil was collected from river bed whose properties are shown in Table 1. The soil thus collected was air dried and tested for gradation, Atterberg limits and specific gravity as per IS:

Table 1 Properties of soil sample

Properties	Value
Coarse sand, %	2
Fine sand, %	16
Clay and silt, %	82
Specific gravity	2.68
Liquid limit, %	69
Plastic limit, %	30
Plasticity index, %	39
Max. Dry unit weight, kN/m^3	16.25
Optimum moisture content, %	16
Plasticity classification	CH

Table 2 Properties of fly ash

Parameters	Value
LOI	0.65
Silica (SiO_2)	64.34%
Alumina (Al_2O_3)	24.06%
Iron Oxide (Fe_2O_3)	4.36%
Titanium Oxide (TiO_2)	0.90%
Calcium Oxide (CaO)	2.30%
Magnesium Oxide (MgO)	1.09%
Sodium Oxide (Na_2O)	0.89%
Potassium Oxide (K_2O)	1.06%
Others	1.00%

Table 3 Properties of human hair fibre

Property	Value
Average length	4-40 mm
Average diameter	40-111 μm

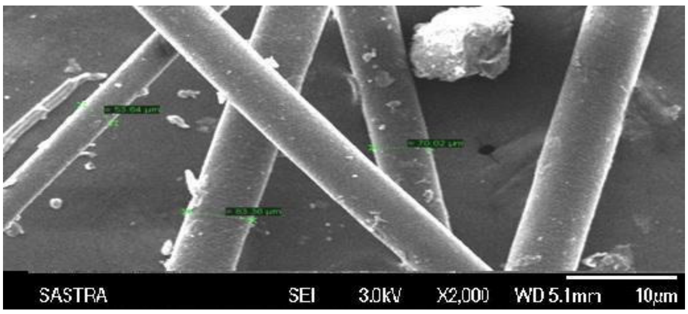

Fig. 1 View of SEM micrograph of human hair fiber

2720 (part 4)-1985, (part 5)-1985 and (part 3/sec-1)-1980 respectively. The properties of fly ash and HHF used in this study are shown in Tables 2 and 3 respectively. Scanning Electron Microscope analysis was conducted to obtain the average diameter of the human hair fiber used in this study. Fig. 1 shows the SEM image of the HHF from which the diameter of the human hair fiber was measured.

3. Laboratory tests and program

Air -dried soil samples were used for the test. The Consistency limits were determined as per IS: 2720 (part 5) – 1985.The first series of laboratory tests were aimed at determining the optimum proportion of soil and fly ash mixture. Secondly, tests were carried out to determine the proctor compaction properties, UCC strength and CBR of the optimized mixture upon mixing with varying percentage of HHF. Different percentages of fiber content added to the optimized soil fly ash mixture were 0.25%, 0.5%, 0.75% and 1.00% by weight of oven dried sample. From Fig. 2, it is clear that when the natural soil is replaced with 5% FA, the maximum dry density increased from 16.25 kN/m^3 to 17.3 kN/m^3 and the OMC decreased from 16% to 13%. Hence, different percentages of fibers added to the soil – fly ash mixture were compacted to the maximum dry density of 17.3 kN/m^3 with an optimum moisture content of 13% and tested. All mixing was done manually and proper care and time were spent for preparing homogenous mixture at each stage of mixing.

4. Results and discussions

4.1 Effect of fly ash on compaction characteristics of soil

The variation of maximum dry density and optimum moisture content with different percentage of fly ash is studied and presented in Fig. 2. The maximum dry density increased and optimum moisture content decreased with increasing fly ash content up to 5% and this showed a reverse

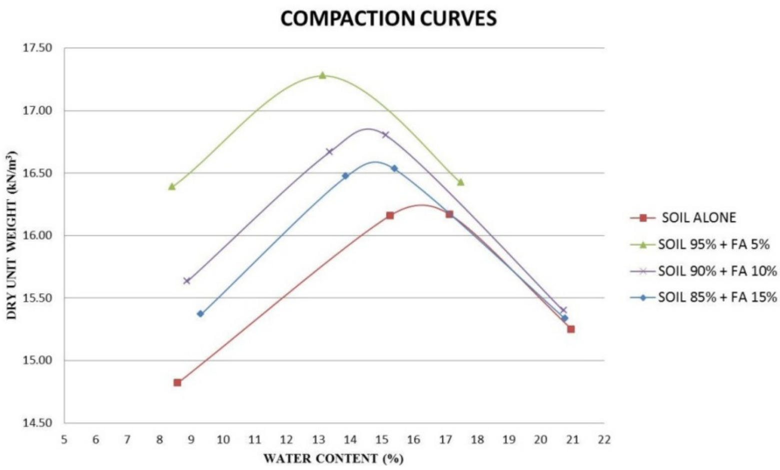

Fig. 2 Compaction curves for different percentage of fly ash content

trend beyond 5%. The maximum dry density of natural soil increased from 16.25 kN/m^3 to 17.3 kN/m^3 for 5% fly ash replacement and then decreased to 16.6 kN/m^3 as in case of 10% fly ash replacement. The optimum water content reduces with increasing fly ash content because the cation exchange between additives and expansive soil decreases the thickness of electric double layer and promotes the flocculation.

4.2 Effect of fly ash on UCC strength

From Fig. 3, it can be inferred that the UCC strength of soil is 171.7 kN/m^2 and 141.24 kN/m^2 respectively for 5% and 10% replacement of FA whereas soil alone yielded 99.71 kN/m^2. Hence the strength gets increased to 72.2%, 41.7% with addition of 5%, and 10% of fly ash respectively. The increase in strength of soil can be attributed to the main attractive property of fly ash which is nothing but its pozzolanic nature.

4.3 Load – Penetration curves of soil and FA mix

The CBR values for different compositions were obtained by compacting the mixture to MDD

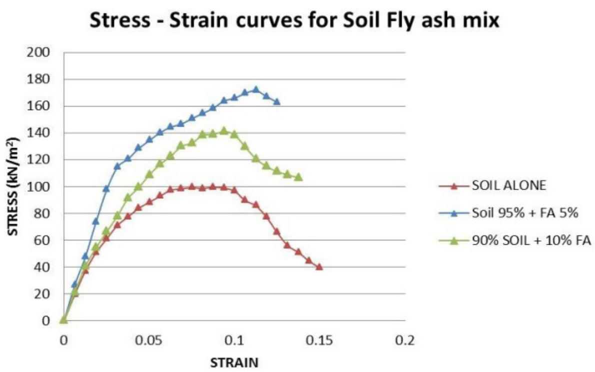

Fig. 3 Stress-Strain curves for different soil-FA mix

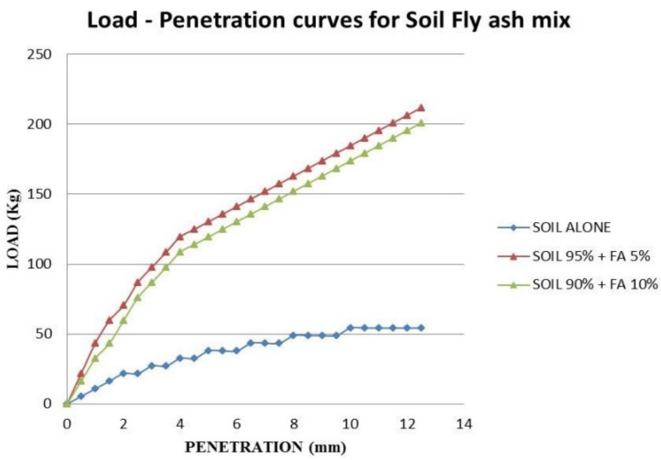

Fig. 4 Load-Penetration curves for soil-FA mix

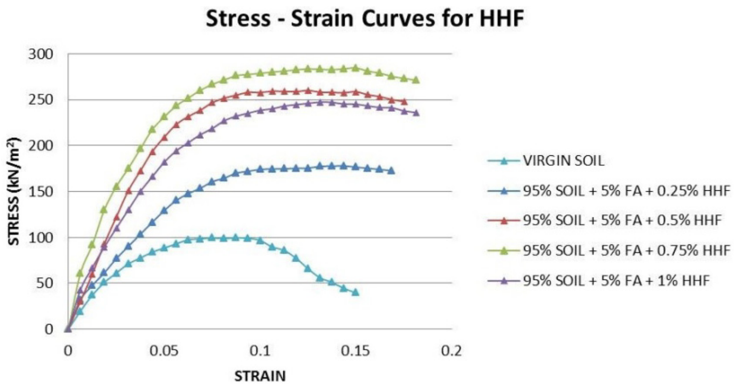

Fig. 5 Stress-Strain curves for 95% soil - 5% FA mix with different percentage of HHF reinforcement

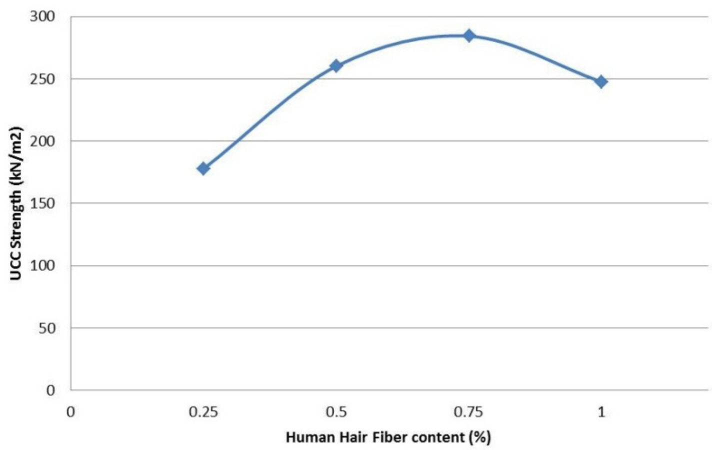

Fig. 6 Effect of HHF on UCC strength of 95% soil - 5% FA mix

and OMC corresponding to IS light compaction and tested in un-soaked conditions. It can be observed from the Fig. 4 that addition of fly ash adds to the strength of soil and it increased the piston load at given penetration. CBR of soil increased from 1.59% to 6.34% at 5% replacement of fly ash which is almost 298% increase in strength.

4.4 Stress-strain behaviour of human hair fibers in optimised mixture

The stress-strain characteristics of optimised soil-fly ash mixture reinforced with varying percentage of Human Hair fibers are presented in Fig. 5.

The UCC strength of soil-fly ash mixture are 177.93 kN/m^2, 260.2 kN/m^2, 284.24 kN/m^2, 247.45 kN/m^2 respectively for varying percentages of HHF of 0.25%, 0.5%, 0.75%, 1% respectively whereas soil alone yielded 99.71 kN/m^2. Hence the strength gets increased to 78.44%, 160.95%, 185.06%, and 148.16% with addition of 0.25%, 0.5%, 0.75% and 1% of HHF respectively.

Fig. 6 indicates that there is a decline in the UCC strength value beyond 0.75% reinforcement

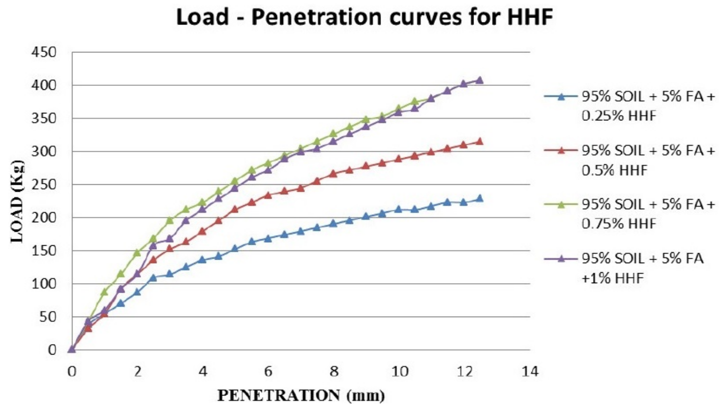

Fig. 7 Load-Penetration curves for optimised soil fly ash mix reinforced with various percentages of HHF

of HHF which could be attributed to the lack of binding and interlocking due to the surplus reinforcement of fibers. Hence 0.75% of HHF is found to be optimum in 95% soil - 5% FA mixture.

4.5 Load – penetration curves of soil-FA mix reinforced with HHF

The CBR tests were performed for various percentages of HHF under un-soaked condition and the load-displacement response for reinforced soil is shown in the Fig. 7.

It is evident from the above figure that inclusion of fibers increased the CBR value appreciably. The maximum value of CBR is 12% which is obtained for 0.75% reinforcement of Human Hair fibers.

4.6 Effect of fly ash and HHF on California ratio gain factor (*CRGF*)

For better understanding of the effect of fly ash and HHF on CBR, a non-dimensional parameter, CALIFORNIA RATIO GAIN FACTOR (CRGF), which is the indicator of strength increase, has been introduced. California ratio gain factor is the ratio of CBR of reinforced soil-fly ash mixture to the CBR of untreated soil. Fig. 8 presents the variation of California Ratio Gain

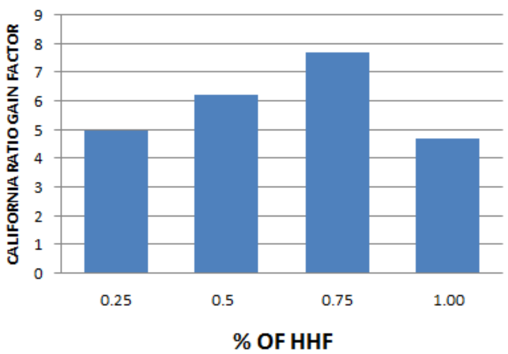

Fig. 8 Variation of California ratio gain factor with % of HHF

Factor with the percentage increase in HHF. The California ratio gain factor was found to be 4.97, 6.23, 7.73 and 4.7 for 0.25%, 0.5%, 0.75% and 1% of reinforcement of HHF content. Hence , we could see that the soil- fly ash mixture reinforced with 0.75% of Human hair fibres have yielded the maximum CRGF of 7.73.

5. Microstructural analysis using Scanning Electron Microscope (SEM)

The changes of microstructures and microstructural development of soils play a significant role in the geotechnical properties and mechanical behaviour of stabilized soils. The changes of the microstructures of soil due to addition of fly ash were investigated using JSM 6701F Scanning Electron Microscope operated at 3 KV. The samples as prepared for unconfined compression test were prepared for both natural and 5% fly ash stabilized soils and the specimens were broken and air dried for 2 days to analyse the microstructures.

Fig. 9 show the SEM Micrographs of natural untreated clay which indicates the sheet like

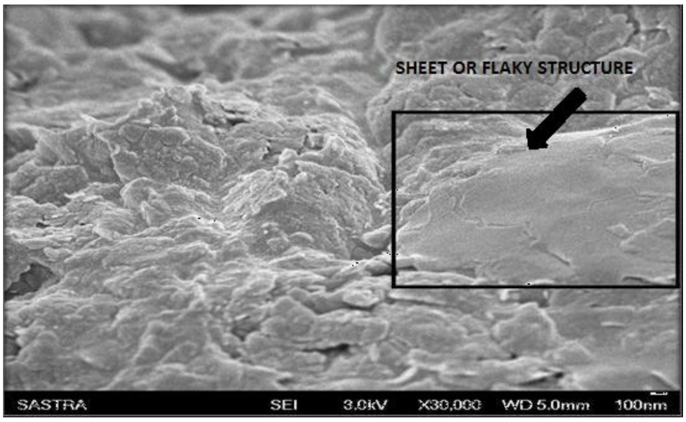

Fig. 9 SEM Micrograph of virgin clay at X30000 magnification

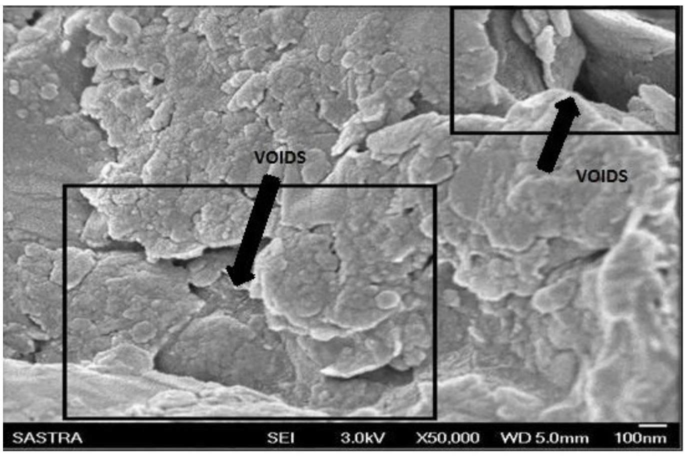

Fig. 10 SEM Micrograph of virgin clay at X50000 magnification

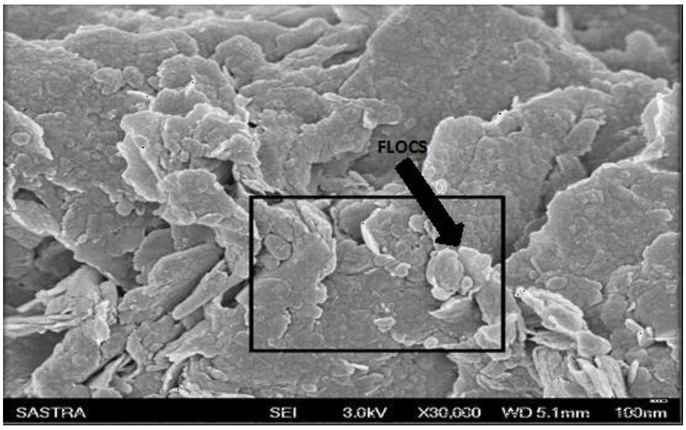

Fig. 11 SEM Micrograph of 5% FA treated clay at X30000 magnification

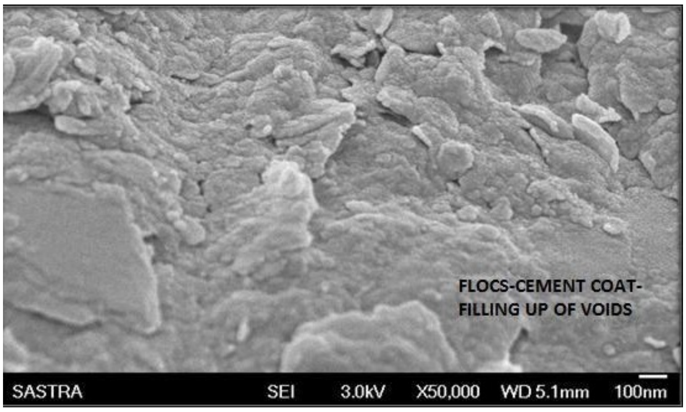

Fig. 12 SEM Micrograph of 5% FA treated clay at X50000 magnification

structure and flaky arrangement of clay particles at X30000 magnification. Also from Fig. 10 we can observe the occurrence of large void spaces in the specimen at higher magnification of X50000.

Figs. 11 and 12 show the SEM Micrographs of 5% fly ash treated clay which indicates the change in morphology of structure of natural untreated clay from flaky structure to flocculated structure as in case of 5% fly ash treated clay. The crumbs of floccules and cementitious compounds coated the clay particles. The cementitious compounds thus formed as a result of hydration reaction joined both the soil and fly ash particles as a network and it also filled up the void spaces partially between the particles.

Thus it is clear that in 5% fly ash treated soil clay particles transformed from a flaky form into a flocculating form. The sufficient gel like cementitious compounds due to the pozzolanic reaction binds the soil and fly ash particles together making the voids in the soil less distinct thereby increasing the strength of the soil. Thus microstructural analysis is in agreement with the results of strength tests.

6. Conclusions

The optimised proportion of soil-fly ash mixture is reinforced with different percentage of HHF and UCC strength and CBR tests were conducted in these mixtures and following conclusions were drawn:

(1) 95% soil in combination with 5% fly ash was found to be the optimized soil – fly ash mixture which yielded a maximum dry density of 1.73 g/cc and an optimum moisture content of 13%.
(2) Based on the results, it was observed that there is 72% increase in Unconfined Compressive Strength and 298% increase in CBR of soil with replacement of 5% fly ash alone. This can be attributed to the hydration reaction that takes place between free calcium oxide in fly ash and water which results in the formation of gel like compounds which binds the soil and fly ash together and offer resistance to shear.
(3) In the specimen of natural untreated clay, failure was by bulging and the tensile cracks were prominent. When fly ash was added in different percentages, the bulging got reduced but the tensile cracks occurred. The bulging as reduced by fly ash may be due to the cation exchange and flocculation which resulted in the reduction of electric double layer.
(4) On the addition of HHF to the optimized mix, the tensile cracks got reduced and at 0.75% reinforcement of it, the cracks were almost not evident. The reduction in tensile cracks may be due to the pull out resistance offered by the fibers that bridge the gap and reduce the tensile cracks.
(5) The 0.75% HHF reinforced mix yielded an increase in strength of about 66% for UCC and about 94% for CBR compared to the optimized soil fly ash mixture. This could be greatly pronounced for adhesion between HHF and soil-fly ash mixture, surface roughness of fiber, effective contact area at interface, interfacial bond strength and the associated friction.
(6) The UCS and CBR value of 0.75% HHF reinforced mix are nearly 2.85 times and 7.73 times greater than that of the untreated soil.

Hence it can be concluded that the Human Hair fibers can be used advantageously for pavements. However the preference could be given based on priorities for service life, economy and environment.

References

Aggarwal, P. and Sharma, B. (2011), "Application of jute fiber in the improvement of subgrade characteristics", *ACEEE Int. J. Transport. Urban Develop.*, **1**(1), 56-58.

Akhtar, J.N., Alam, J. and Ahmad, Sh. (2008), "The influence of randomly oriented hair fibre and lime on the CBR value of Dadri fly ash", *Asian J. Civil Eng.* (*Build. Hous.*), **9**(5), 505-512.

Al-Refeai, T.O. (1991), "Behaviour of granular soil reinforced with discrete randomly oriented inclusions", *Geotext. Geomembr.*, **10**(4), 319-333.

Bose, B. (2012), "Geo-engineering properties of expansive soil stabilized with fly ash", *Electro. J. Geotech. Geoenviron. Eng.*, **17**, 1339-1353.

Chakraborty, T.K. and Dasgupta, S.P. (1996), "Randomly reinforced fly ash as foundation material", *Indian Geotechnical Conference*, **1**, 231-235.

Chauhan, M.S., Mittal, S. and Mohanty, B. (2008), "Performance evaluation of silty sand sub grade reinforced with flyash and fiber", *Geotext. Geomembr.*, **26**(5), 429-435.

Edil, T.B., Acosta, H.A. and Benson, C.H. (2006), "Stabilizing soft fine grained soils with fly ash", *J. Mater. Civil Eng.*, *ASCE*, **18**(2), 283-294.
Hasan, H.A. (2012), "Effect of fly ash on geotechnical properties of soil", *J. Eng. Develop.*, **16**(2), 306 -316.
Jiang, H., Cai, Y. and Liu, J. (2010), "Engineering properties of soils reinforced by short discrete polypropylene fiber", *J. Mater. Civil Eng.*, **22**(12), 1315-1322.
Kaniraj, S.R. and Gayatri, V. (2003), "Geotechnical behavior of fly ash mixed with randomly oriented fiber inclusions", *Geotext. Geomembr.*, **21**(3), 123-149.
Kaniraj, S.R. and Havanagi, V.G. (2001), "Behavior of cement stabilized fiber reinforced fly ash soil mixtures", *J. Geotech. Geoenviron. Eng.*, *ASCE*, **127**(7), 574-584.
Maher, M.H. and Gray, D.H. (1990), "Static response of sands reinforced with randomly distributed fibers", *J. Geotech. Eng. Div.*, *ASCE*, **116**(11), 1661-1667.
Maher, M.H. and Ho, Y.C. (1994), "Mechanical properties of kaolinite/fiber soil composite", *J. Geotech. Eng.*, *ASCE*, **120**(8), 1381-1393.
Mali, S. and Singh, B. (2014), "Strength behaviour of cohesive soils reinforced with fibres", *Int. J. Civil Eng. Res.*, **5**(4), 353-360.
Phanikumar, B.R. and Sharma, R.S. (2004), "Effect of flyash on engg properties of expansive soil", *J. Geotech. Geoenviron. Eng.*, **130**(7), 764-767.
Pillai, R.R. and Ramanathan, A. (2012), "An innovative technique of improving the soil using human hair fibers", *Proceedings of the 3rd International Conference on Construction in Developing Countries* (*ICCIDC–III*); *Advancing Civil, Architectural and Construction Engineering & Management*, Bangkok, Thailand, July.
Prabakar, J., Dendorkar, N. and Morchhale, R.K. (2004), "Influence of fly ash on strength behaviour of typical soils", *Construct. Build. Mater.*, **18**(4), 263-267.
Pradhan, P., Karand, R. and Naik, A. (2012), "Effect of random inclusion of polypropylene fibres on strength characteristics of cohesive soil", *Geotech. Geol. Eng.*, **30**(1), 15-25.
Shewbridge, S.E. and Sitar, N. (1989), "Deformation characteristics of reinforced sand in direct shear", *J. Geotech. Eng.*, *ASCE*, **115**(8), 1134-1147.
Sivakumar Babu, G. and Vasudevan, A.K. (2008), "Strength and stiffness response of coir fiber-reinforced tropical soil", *J. Mater. Civil Eng.*, **20**(9), 571-577.
Sivakumar Babu, G. and Chouskey, S.K. (2010), "Model analysis of fibre reinforced clayey soil", *Geomech. Geoeng. J.*, **5**(4), 277-285.

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