International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 02 Issue: 05 | Aug-2015 www.irjet.net p-ISSN: 2395-0072

Utilization of Industrial Wastes for Production of Black Cotton Soil Bricks

Dr. T. Sekar
Professor of Civil Engineering, University College of Engineering, Ramanathapuram – 623 513, Tamil Nadu, India.

---***---

Abstract - *An experimental investigation has been carried out to study the feasibility of producing bricks from locally available black cotton soil (also called black soil) using industrial waste materials such as fly ash and granite waste. In order to study the various engineering properties of bricks, a total of 594 numbers of brick specimens of 210x100x70mm size were prepared in three series by combining black soil, fly ash and granite waste in different proportions. The brick specimens were then air dried, baked in kiln and tested for compressive strength, water absorption, efflorescence and weight density as per IS 3495 code procedure. For comparison purpose, 18 numbers of conventional burnt clay bricks, and 18 numbers of pressed type water cured cement fly ash bricks were also tested for the aforesaid brick properties. Test results obtained in the present investigation indicate that it is possible to manufacture good quality bricks using locally available black soil by suitably adding either fly ash or granite waste or both, and such bricks can be used in lieu of conventional burnt clay bricks or pressed type water cured cement fly ash bricks presently in use for various construction activities across the country.*

Key Words: *Black soil, Fly ash, Granite waste, Brick manufacturing, Brick properties, Feasibility study.*

1. INTRODUCTION

The common burnt clay brick is one of the oldest building materials, and is being extensively used even today as a leading construction material because of its strength, durability and low cost. Demand for this brick in our country is increasing day-by-day because of the aforesaid favourable characteristics and brisk construction activities. Black soil is one of the major soil deposits in India covering an area of about 5.4 lakh square kilometer i.e. 16.6% of the total land area of our country [1, 2]. Ramanathapuram district in Tamilnadu state has a total land area of 4123 square kilometer, and the black soil deposits in the district constitute about 46% of the land area [3, 4]. Because of the extensive black soil deposits in the Ramanathapuram district, at present, there are no large-scale brick manufacturing kilns available to cater to the needs of various construction activities in and around Ramanathapuram and Rameswaram regions, and people living in these regions rely on kilns available in the nearby areas which are about 40 to 100km away from the Ramanathapuram/Rameswaram city. This increases the cost of bricks, and hence the overall cost of projects in these regions by about 15 to 20%. Generally, quality of bricks mainly depends on the type and quality of raw materials used for manufacturing them. It is a well-established fact that good quality bricks can be manufactured from alluvial/red soil, whereas it is not feasible to manufacture bricks from raw black soil. This is mainly due to the following two reasons: (i) the black soil is highly expansive and sticky in nature when it comes in contact with water, and hence it is very difficult to mix and pug the soil, and (ii) the black soil shrinks heavily and develops large number of wide cracks when allowed to dry, and hence bricks made from black soil lose their dimensional stability and overall integrity. Therefore, in order to overcome the above two major problems, mineral admixtures are commonly added to treat/stabilize the black soil to manufacture bricks.

Various mineral admixtures available to stabilize and improve the engineering properties of black soil are: cement, lime, sand, micro silica, slag, fly ash, rice husk ash, groundnut shell ash, bagasse ash, granite waste, marble waste, crusher waste, cement kiln waste, carbide waste, tile waste, ceramic waste, polyvinyl waste, steel mill scale waste, etc. Stabilization of black soil is often achieved either by using only one mineral admixture [5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16] or by using more than one mineral admixture [17, 18, 19, 20, 21, 22, 23]. Now-a-days, cement stabilization is not preferable because of its high cost and environmental problems associated with its production. Lime stabilization is also not suitable for soils which contain sulphates. Presence of sulfates can increase the swelling behavior of black soil due to the formation of swelling minerals such as ettringite and thaumasite [24]. Also, mineral admixtures like sand, micro silica and slag are scarce and costlier, and hence their usage as a stabilizing agent is not advisable. However, mineral admixtures like fly ash (*a waste material from thermal power plants*) and granite waste (*a waste material from granite cutting and polishing industries*) are cheaper and easily available in abundance in the nearby regions when compared to the other ash-type/waste-type mineral admixtures cited above.

Furthermore, fly ash and granite waste are industrial waste materials and they are simply dumped near the plants on large hectares of fertile land. These wastes cause environmental problem, contaminate ground water quality and also cause serious health hazard to the people living in the nearby areas. Disposal of these wastes is a rapidly growing problem and effective utilization of these wastes converts them into useful products besides saving natural resources, and can also alleviate the disposal and environmental problems to a great extent. Therefore, in the present work, an attempt has been made to experimentally investigate the feasibility of producing bricks from locally available black soil using low cost industrial waste materials such as fly ash and granite waste. Test results obtained in this investigation are presented and discussed in this paper.

2. MATERIALS USED

Following are the materials used in this experimental investigation:

1. Black soil - Black soil available in the college premises having a specific gravity of 2.67, fineness modulus of 2.49, optimum moisture content of 20%, liquid limit of 73.68%, plastic limit of 29.10% and shrinkage limit of 12%.
2. Fly ash - Fly ash obtained from Tuticorin thermal power plant having a specific gravity of 2.54, fineness modulus of 2.39 and bulk density of 10.6kN/m^3.
3. Granite waste - Granite waste obtained from a granite cutting and polishing industry having a specific gravity of 2.75, fineness modulus of 3.44 and bulk density of 13.3kN/m^3.
4. Water - Water available in the college premises having a pH value of 8.26.

3. EXPERIMENTAL INVESTIGATION

In the present experimental investigation, a total of 594 numbers of brick specimens were cast in three series by combining locally available black soil in the Ramanathapuram region with low cost industrial waste materials such as fly ash and granite waste in different proportions. In series 1, black soil and fly ash were combined, whereas in series 2, black soil and granite waste were combined. But, in series 3, black soil, fly ash and granite waste were combined. The details regarding the combination ratios, the number of brick specimens cast to evaluate various engineering properties of bricks are presented in table 1. For casting the brick specimens, the required quantity of materials as per the combination ratios cited in table 1 were first taken on weight basis in dry condition. The dry materials were then mixed thoroughly by adding sufficient quantity of water until homogenous as well as workable mix was obtained. Wooden moulds of 210x100x70mm size were used for casting brick specimens. Figs. 1 to 3 show typical brick specimens cast in the present work. The cast brick

Table - 1: Details of brick specimens cast

Specimen details	Specimen designation	Percentage combination of black soil, fly ash and granite waste (*by weight*)			No. of speci-mens cast to conduct			Total No. of specimens cast	
		Black soil	Fly ash	Granite waste	Strength test	Absorption test	Efflorescence test	Column (1)	Column (2)
Brick specimens cast using black soil and fly ash (*i.e. Series 1*)	B S_{100} A_0	100%	0%	-	6	6	6	18	198
	B S_{90} A_{10}	90%	10%	-	6	6	6	18	
	B S_{80} A_{20}	80%	20%	-	6	6	6	18	
	B S_{70} A_{30}	70%	30%	-	6	6	6	18	
	B S_{60} A_{40}	60%	40%	-	6	6	6	18	
	B S_{50} A_{50}	50%	50%	-	6	6	6	18	
	B S_{40} A_{60}	40%	60%	-	6	6	6	18	
	B S_{30} A_{70}	30%	70%	-	6	6	6	18	
	B S_{20} A_{80}	20%	80%	-	6	6	6	18	
	B S_{10} A_{90}	10%	90%	-	6	6	6	18	
	B S_0 A_{100}	0%	100%	-	6	6	6	18	
Brick specimens cast using black soil and granite waste (*i.e. Series 2*)	B S_{100} W_0	100%	-	0%	6	6	6	18	198
	B S_{90} W_{10}	90%	-	10%	6	6	6	18	
	B S_{80} W_{20}	80%	-	20%	6	6	6	18	
	B S_{70} W_{30}	70%	-	30%	6	6	6	18	
	B S_{60} W_{40}	60%	-	40%	6	6	6	18	
	B S_{50} W_{50}	50%	-	50%	6	6	6	18	
	B S_{40} W_{60}	40%	-	60%	6	6	6	18	
	B S_{30} W_{70}	30%	-	70%	6	6	6	18	
	B S_{20} W_{80}	20%	-	80%	6	6	6	18	
	B S_{10} W_{90}	10%	-	90%	6	6	6	18	
	B S_0 W_{100}	0%	-	100%	6	6	6	18	
Brick specimens cast using black soil, fly ash and granite waste (*i.e. Series 3*)	B S_{100} A_0 W_0	100%	0%	0%	6	6	6	18	198
	B S_{90} A_5 W_5	90%	5%	5%	6	6	6	18	
	B S_{80} A_{10} W_{10}	80%	10%	10%	6	6	6	18	
	B S_{70} A_{15} W_{15}	70%	15%	15%	6	6	6	18	
	B S_{60} A_{20} W_{20}	60%	20%	20%	6	6	6	18	
	B S_{50} A_{25} W_{25}	50%	25%	25%	6	6	6	18	
	B S_{40} A_{30} W_{30}	40%	30%	30%	6	6	6	18	
	B S_{30} A_{35} W_{35}	30%	35%	35%	6	6	6	18	
	B S_{20} A_{40} W_{40}	20%	40%	40%	6	6	6	18	
	B S_{10} A_{45} W_{45}	10%	45%	45%	6	6	6	18	
	B S_0 A_{50} W_{50}	0%	50%	50%	6	6	6	18	
								Grand Total	594
Clay bricks (*for comparison purpose*)					6	6	6	18	18
Fly ash bricks (*for comparison purpose*)					6	6	6	18	18

Note: For instance, B S_{60} A_{20} W_{20} means brick specimen made with 60% black soil, 20% fly ash and 20% granite waste.

specimens were then allowed to dry for a period of 2 weeks, so that moisture present in the green brick specimens evaporates. Then the brick specimens were baked in a kiln for about 24 hours at 600 to 800^{0}C, and then allowed to cool in a gradual manner for a period of 2 weeks. The burnt brick specimens were then taken out from the kiln, and then tested for compressive strength, water absorption, efflorescence and weight density in the laboratory as per IS 3495 code procedure [25]. For comparison purpose, 18 numbers of ordinary burnt clay bricks (*also called clay bricks*), and 18 numbers of pressed-type water cured cement fly ash bricks (*also called fly ash bricks*) commonly used for the construction activities were also tested for various brick properties (*vide Table 1*).

4. RESULTS AND DISCUSSION

Test results obtained for fly ash added (*i.e. treated or stabilized*) black soil bricks, granite waste added black soil bricks, and both fly ash and granite waste added black soil bricks are presented in table 2. In addition, for comparison purpose, test results obtained for clay bricks and fly ash bricks are also presented in the above table. The results reported are average value of 6 specimens. The individual effect of addition of fly ash or granite waste, and the combined effect of addition of both fly ash and granite waste on various engineering properties of black soil bricks are discussed in the succeeding sections.

4.1 Effect of fly ash

During the experimental investigation conducted in series 1, it was observed that the brick specimens made by combining soil and ash in the proportions of (100:0), (90:10), (80:20) and (70:30) have developed cracks at the end of air drying process. This shows that the shrinkage characteristics of black soil cannot be completely eliminated by adding fly ash from 0 to 30%. Also, it was observed that the brick specimens made by combining soil and ash in the proportion of (0:100) were in the form of powder at the end of air drying process. This may be attributed to absolute absence of black soil. The total absence of black soil failed to combine all the particles present in the specimen together. In addition, it was observed that the brick specimens made by combining soil and ash in the proportions of (20:80) and (10:90) have resulted in partial or complete damage when such specimens were kept in water for water absorption/efflorescence test. This may possibly be due to non-uniform or inadequate baking of specimens in the kiln, or due to the presence of very small quantity of black soil in the specimens. Furthermore, no formation of white patches (*i.e. deposits*) was noticed on the surfaces of all the specimens tested for efflorescence. This indicates the absence of water soluble salts in the locally available black soil.

Fig - 1: Brick specimens B S_{40} A_{60}

Fig - 2: Brick specimens B S_{50} W_{50}

Fig - 3: Brick specimens B S_{30} A_{35} W_{35}

Therefore, it is evident from the present investigation that it is not feasible to make bricks from locally available black soil by adding fly ash either up to 30% or beyond 70%. However, it is possible to make bricks using locally available black soil by adding fly ash from 40 to 70%, and bricks produced using the above range have shown compressive strength ranging from 2.62N/mm² to 5.48N/mm², water absorption ranging from 12% to 14% and density ranging from 14.25kN/m³ to 16.07kN/m³. Similarly, it is observed from the present investigation that the brick specimens made by combining 50% of soil and 50% of ash (i.e. 1:1 ratio) have shown a higher compressive strength of 5.48N/mm², lower water absorption of 12% and higher density of 16.07kN/m³ when compared to the values obtained for all other combinations investigated in this series 1, and hence it is the optimum combination. Hence, good quality bricks can be prepared by combining black soil and fly ash in equal proportion.

4.2 Effect of granite waste

Like the observations made in series 1, it was observed during the investigation conducted in series 2 that the specimens made by combining soil and waste in the proportions of (100:0), (90:10), (80:20) and (70:30) have developed cracks, the specimens made by combining 0% soil and 100% waste were in powder form, the specimens made by combining soil and waste in the proportions of (20:80) and (10:90) have failed partially or completely, and also no formation of white deposits was noticed on the surfaces of specimens tested for efflorescence. Hence, similar to the soil-ash bricks, soil-waste bricks can also be made by adding granite waste from 40 to 70%, and bricks produced using the above range have shown compressive strength ranging from 3.65N/mm² to 5.50N/mm², water absorption ranging from 11% to 17% and density ranging from 14.60kN/m³ to 16.25kN/m³. The bricks made by combining 40% soil and 60% waste (i.e. 1:1.5 ratio) have shown a higher compressive strength of 5.50N/mm², lower water absorption of 11% and higher density of 16.25kN/m³ when compared to the values obtained for all other combinations investigated in this series 2, and hence it is the optimum combination. Hence, good quality bricks can be made by combining soil and waste in the ratio of (1:1.5).

4.3 Combined effect of fly ash and granite waste

It was found during the investigation conducted in series 3 that the specimens made by combining soil, ash and waste in the proportions of (100:0:0), (90:5:5), (80:10:10) and (70:15:15) have developed cracks, the specimens made by combining 0% soil, 50% ash and 50% waste were in powder form, the specimens made by combining soil, ash and waste in the proportions of (20:40:40) and (10:45:45)

Table - 2: Summary of test results

Specimen details	Specimen designation	Percentage combination of black soil, fly ash and granite waste (*by weight*)			Compressive strength (N/mm²)	Water absorption (%)	Efflorescence	Density (kN/m³)
		Soil	Ash	Waste				
Specimens made by soil and ash	B S_{100} A_0	100%	0%	-	*			
	B S_{90} A_{10}	90%	10%	-	*			
	B S_{80} A_{20}	80%	20%	-	*			
	B S_{70} A_{30}	70%	30%	-	*			
	B S_{60} A_{40}	60%	40%	-	4.71	14	Nil	15.85
	B S_{50} A_{50}	50%	50%	-	5.48	12	Nil	16.07
	B S_{40} A_{60}	40%	60%	-	4.53	13	Nil	15.51
	B S_{30} A_{70}	30%	70%	-	3.81	13	Nil	15.03
	B S_{20} A_{80}	20%	80%	-	3.38	**	**	14.62
	B S_{10} A_{90}	10%	90%	-	2.62	**	**	14.25
	B S_0 A_{100}	0%	100%	-	***			
Specimens made by soil and waste	B S_{100} W_0	100%	-	0%	*			
	B S_{90} W_{10}	90%	-	10%	*			
	B S_{80} W_{20}	80%	-	20%	*			
	B S_{70} W_{30}	70%	-	30%	*			
	B S_{60} W_{40}	60%	-	40%	4.33	17	Nil	14.60
	B S_{50} W_{50}	50%	-	50%	5.23	14	Nil	15.57
	B S_{40} W_{60}	40%	-	60%	5.50	11	Nil	16.25
	B S_{30} W_{70}	30%	-	70%	4.52	12	Nil	15.95
	B S_{20} W_{80}	20%	-	80%	3.95	**	**	15.80
	B S_{10} W_{90}	10%	-	90%	3.65	**	**	15.68
	B S_0 W_{100}	0%	-	100%	***			
Specimens made by soil, ash and waste	B S_{100} A_0 W_0	100%	0%	0%	*			
	B S_{90} A_5 W_5	90%	5%	5%	*			
	B S_{80} A_{10} W_{10}	80%	10%	10%	*			
	B S_{70} A_{15} W_{15}	70%	15%	15%	*			
	B S_{60} A_{20} W_{20}	60%	20%	20%	3.54	16	Nil	15.39
	B S_{50} A_{25} W_{25}	50%	25%	25%	4.57	13	Nil	16.17
	B S_{40} A_{30} W_{30}	40%	30%	30%	5.71	10	Nil	16.78
	B S_{30} A_{35} W_{35}	30%	35%	35%	4.10	12	Nil	16.63
	B S_{20} A_{40} W_{40}	20%	40%	40%	3.77	**	**	16.41
	B S_{10} A_{45} W_{45}	10%	45%	45%	3.11	**	**	16.73
	B S_0 A_{50} W_{50}	0%	50%	50%	***			
Clay bricks (*for comparison purpose*)					5.93	15	Nil	14.82
Fly ash bricks (*for comparison purpose*)					6.23	10	Nil	17.63

Note: * These specimens developed cracks during air drying stage, and hence they could not be taken to kiln for baking.
** These specimens were partly/completely damaged when they were in water during test.
*** These specimens were in powder form, and hence they could not be taken to kiln for baking.

have resulted in partial damage or complete collapse, and also no formation of white deposits was noticed on the surfaces of specimens tested for efflorescence. Hence, it is clear that it is possible to make bricks by adding both fly ash and granite waste from 20 to 35%, and bricks produced using the above range have shown compressive strength ranging from 3.11N/mm^2 to 5.71N/mm^2, water absorption ranging from 10% to 16% and density ranging from 15.39kN/m^3 to 16.78kN/m^3. The bricks made by combining 40% soil, 30% ash and 30% waste (i.e. 1:0.75:0.75 ratio) have shown a higher compressive strength of 5.71N/mm^2, lower water absorption of 10% and higher density of 16.78kN/m^3 when compared to the values obtained for all other combinations investigated in this series 3, and hence it is the optimum combination. Hence, good quality bricks can be prepared by combining soil, ash and waste in the ratio of (1:0.75:0.75).

4.4 Comparison of stabilized black soil bricks with conventional bricks

It is seen from the results presented in table 2 that the values of compressive strength, water absorption and density obtained for soil-ash, soil-waste and soil-ash-waste bricks at the optimum combination ratios are 5.48N/mm^2, 12% & 16.07kN/m^3; 5.50N/mm^2, 11% & 16.25kN/m^3; and 5.71N/mm^2, 10% & 16.78kN/m^3, respectively. The corresponding values obtained for the clay bricks are 5.93N/mm^2, 15% & 14.82kN/m^3, and for the fly ash bricks are 6.23N/mm^2, 10% and 17.63kN/m^3, respectively. Thus, it is clear that the results obtained on various engineering properties of stabilized black soil bricks at the optimum combination ratios in all the three series investigated in this study are in good agreement with the results obtained for clay bricks and also for fly ash bricks. Besides, stabilized black soil bricks produced from all the three series cases are having compressive strength values higher than 3.5N/mm^2 and water absorption values less than 20%. Since these values satisfy the values recommended in IS 1077 code [26], bricks made by using any of the three combination cases can be used for the construction activities. Hence, fly ash and/or granite waste stabilized black soil bricks is a viable alternative to the conventional clay or fly ash bricks.

5. CONCULUSIONS

Based on the experimental investigation carried out in this work, the following conclusions can be drawn:

i. It is possible to manufacture good quality bricks from locally available black soil in Ramanathapuram region using industrial waste material either fly ash or granite waste or both.
ii. The optimum combination ratios to manufacture bricks with higher compressive strength, lower percentage of water absorption and higher weight density for the soil-ash, soil-waste, and soil-ash-waste combinations are (1:1), (1:1.5) and (1:0.75:0.75), respectively.
iii. Among the three combination cases investigated in this work, the bricks manufactured by soil-ash-waste combination yielded a higher compressive strength of 5.71N/mm^2, lower water absorption of 10% and higher density of 16.78kN/m^3.
iv. The stabilized black soil bricks in all the three series cases have shown compressive strength values higher than 3.5N/mm^2 and water absorption values less than 20%. As these values satisfy the recommendations of IS 1077 code, stabilized black soil bricks made by using either fly ash or granite waste or both can be used for construction activities.
v. Fly ash and granite waste are industrial waste materials and effective utilization of these wastes converts them into useful products besides saving natural resources. Hence, fly ash and/or granite waste stabilized black soil bricks stand as a promising alternative to conventional clay or fly ash bricks, and can be manufactured on large-scale wherever black soil, fly ash and granite waste are available in plenty.

REFERENCES

[1] Geography of India part 1, "*UPSC civil services notes*", Retrieved from http://nagahistory.wordpress.com/2014/05/19/geography-of-india-part-i/
[2] Soils in India: Indian geography, "*Bit4all*", Retrieved from http://www.bit4all.com/topic/soils-types-indian-geography/
[3] Geographical features, "*Ramanathapuram district*", Retrieved from http://www.ramnad.tn.nic.in/geo.htm.
[4] Ramanathapuram district, "*In wikipedia*", Retrieved fromhttp://en.wikipedia.org/wiki/Ramanathapuram_district
[5] Agbede, I.O., and Joel, M., "Effect of carbide waste on the properties of Makurdi shale and burnt bricks made from the admixtures", *American Journal of Scientific and Industrial Research,* 2 (4), 2011, pp. 670 - 673.
[6] Amit S. Kharade, Vishal V. Suryavanshi, Bhikaji S. Gujar, and Rohankit R. Deshmukh, "Waste product 'Bagasse ash' from sugar industry can be used as stabilizing material for expansive soils", *International Journal of Research in Engineering and Technology,* vol. 3, issue 3, 2014, pp. 506 - 512.
[7] Chayan Gupta, and Ravi Kumar Sharma, "Influence of micro silica fume on sub grade characteristics of expansive soil", *International Journal of Civil*

Engineering Research, vol. 5, issue 1, 2014, pp. 77 - 82.

[8] Gyanen.Takhelmayum, Savitha. A.L., and Krisha Gudi, "Laboratory study on soil stabilization using fly ash mixtures", *International Journal of Engineering Science and Innovative Technology,* vol. 2, issue 1, 2013, pp. 477 - 482.

[9] Krishhnamurthy, N. R., Masthanayya, G., and Gopalakrishnayya, A., "Characteristics of fly ash treated black cotton soil bricks", *Journal of the Institution of Engineers (India) – Civil Engineering Division,* vol. 74, 1994, pp. 184 - 186.

[10] Mir, B.A., "Effect of fly ash on swelling potential of BC soil", *Proceedings of Indian Geotechnical Conference on Geotechnical Advances and Noval Geomechanical Applications, December 22 - 24, Roorkee,* 2013, pp. 1 - 9.

[11] Nadgouda, K.A., and Hegde, R.A., "The effect of lime stabilization on properties of black cotton soil", *Indian Geotechnical Conference - 2010,* GEO*trendz, IGS Mumbai Chapter and IIT Bombay, December 16 - 18,* 2010, pp. 511 - 514.

[12] Ogundalu, A.O., Oyekan, G.L., and Meshida. "Effects of steel mill scale on the strength characteristics of expansive clay soils (Black cotton clay soil)", *International Institute for Science, Technology and Education, Civil and Environmental Research,* vol. 3, issue 12, 2013, pp. 52 - 62.

[13] Oriola, F.O.P., and Moses, G., "Compacted black cotton soil treated with cement kiln dust as hydraulic barrier material", *American Journal of Scientific and Industrial Research,* vol. 2, issue 4, 2011, pp. 521 - 530.

[14] Oriola, Folagbade and Moses, G., "Groundnut shell ash stabilization of black cotton soil", *Electronic Journal of Geotechnical Engineering,* vol. 15, Bund. E, 2010, pp. 415 - 428.

[15] Oyekan, G.L., Meshida, E. A., and Ogundalu, A. O., "Effect of ground polyvinyl waste on the strength characteristics of black cotton clay soil", *Journal of Engineering and Manufacturing Technology,* vol. 1, issue 1,, 2013, pp. 1 - 10.

[16] Udayashankar D. Hakari, and Puranik, S.C., "Stabilisation of black cotton soils using fly ash, Hubballi-Dharwad municipal corporation area, Karnataka, India", *Global Journal of Research in Engineering, Civil and Structural Engineering,* vol. 12, issue 2, Version 1.0, 2012, pp. 21 - 29.

[17] Bairwa Ramlakhan, Saxena Anil Kumar, and Arrora, T.R., "Effect of lime and fly ash on Engineering properties of black cotton soil", *International Journal of Emerging Technology and Advanced Engineering,* vol. 3, issue 11, 2013, pp. 535 - 541.

[18] Basha, E.A., Hashim, R., Mahmud, H.B., and Muntohar, A.S., "Stabilization of residual soil with rice husk ash and cement", *Construction and Building Materials,* vol. 19, issue 6, 2005, pp. 448 - 453.

[19] Jagmohan Mishra, Yadav, R.K., and Singhai, A.K., "Effect of granite dust on index properties of lime stabilized black cotton soil", *International Journal of Engineering Research and Science & Technology,* vol. 3, issue 1, 2014, pp. 19 - 23.

[20] Javier Fernando Camacho Tauta, Oscar Javier Reyes Ortiz, Catalina Mayorga Antolinez, and Dolly Fernanda Mendez G, "Evaluation of additives used in treatment of expansive clays", *Universidad Militar Nueva Granada Columbia,* vol. 16, issue 2, 2006, pp. 45 - 53.

[21] Manasseh Joel, and Issac O. Agbede, "Cement stabilization of Igumale shale lime admixture for use as flexible pavement construction material", *Electronic Journal of Geotechnical Engineering, vol.* 15, 2010, pp. 1661 - 1673.

[22] Oza, J.B., and Gundaliya, P.J., "Study of black cotton soil characteristics with cement waste dust and lime", *Procedia Engineering,* vol. 51, 2013, pp. 110 - 118.

[23] Prasad Dahale, and Vaishali J. Rajurkar, "Effect of rice husk ash on lime stabilized black cotton soil", *International Journal of Applied Engineering Research,* vol. 9, issue 2, 2014, pp. 219 - 222.

[24] Rajasekaran, G. "Sulphate attack and ettringite formation in the lime and cement stabilized marine clays", *Ocean Engineering,* vol. 32, issue 8-9, 2005, pp. 1133 - 1159.

[25] IS 3495 (parts 1 to 3) – 1992,. "Methods of tests of burnt clay building bricks (third revision)", *Bureau of Indian standards, New Delhi.*

[26] IS 1077 - 1992, "Common burnt clay building bricks - Specification (fifth revision)", *Bureau of Indian standards, New Delhi.*

BIOGRAPHY

Dr. Sekar is currently working as Professor of Civil Engineering at University College of Engineering, Ramanathapuram, Tamil Nadu, India. He has more than 20 years of teaching experience and contributed more than 60 technical papers in journals and conferences from regional level to international level. His areas of interest include analysis and design of earthquake-resistant, explosion-resistant & tsunami-resistant structures, high performance concrete, fibre reinforced cement composites and cost effective construction materials.