International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 23 (2015)pp43731-43736

Experimental and Analytical Study on the Use of Industrial Wastes/By-Products for Highway Construction

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Abstract
This paper presents and discussesthe results of the experimental and analytical study carried out to explore the possibilities of using combination of industrial wastes/by-products such as waste foundry sand, fly ash and red mud for highwayconstruction. For the experimental study, samples with different percentagesof the industrial wastes/by-products are considered together withone of the stabilizing materials such as cement and lime. Experiments were carried out to determine the strength parameterCalifornia Bearing Ratio (CBR) of the samples. To analyze the results of the experiments hierarchical cluster analysis was carried out in MATLAB. Hierarchical cluster analyses were carried outanddetermined the influence of the percentage of ingredients considered on the strengthof the samples. 20% percentage of fly ash, 10% use of red mud with 5% cement imparted samples were withstood optimum strength than other samples; it is found that by experimentally. Experimental study indicated that, there is a promising future for using the industrial wastes/by-products for highway construction. Cluster analysis revealed that, the percentage of waste foundry sand and fly ash used has predominant effect on the strength of the CBR.

Keywords: Waste Foundry sand, Fly ash, Red mud, Waste management, Industrial by-products

Introduction

Rapid population growth demands increasing infrastructure facilities such as road, bridges etc. Growth of a nation is characterized by the development of industries which, apart from manufacturing useful products for which they are intended for, also results in generation of wastes/by-products. This wastes/by-products if not disposed or used properly endangers the green environment. Efforts are being taken all over the world to achieve sustainable development by finding possible ways of disposing or using the industrial wastes/by-products. Large quantities of materials are needed for road construction and hence, exploring the possible ways of using industrial wastes/by-products in the road construction would be a viable option for achieving sustainable development.

Foundry industries use sands to create moulds wherein molten metal is poured to acquire, upon cooling, required shape and geometry. After repeated use of the moulds, the sands, normally called as foundry sands, become unsuitable for casting process due to loss of required properties. Large quantity of waste foundry sand (WFS) thus generated are normally disposed on the landand hence become threat to the environment. Several research studies are available in the literature [1-4] that have proved, in the presence of stabilizing materials like cement or lime, the feasibility of using WFSforconstruction of highways, retaining walls, landfill liners and pavement bases. Fly ash, a by-product from coal burning thermal power plants, has found to be useful in replacing materials in concrete. With respect to road construction, Dhawan et al. [5] have showed that fly ash can be used as sub-base and sub-grade material. Increase in the shear strength of the soil containing specific percentage of fly ash has been observed by Prabakar et al. [6]. Lav and Lav [7] have reported that stabilization of fly ash is important when it is used in the upper layers of the pavement. Kolias et al. [8] have reported that fly ash, together with cement, may be used to stabilize clayey soil. Trivedi et al. [9] have developed a Genetic Algorithm model to predict the optimum utilization of using fly ash to stabilize sub-grade soil. It is found from these studies that fly ash addition generally increases the engineering performance of the soil.

Red mud is an in-soluble product generated as a by-product in the manufacturing of Aluminium using Beyer's process. Possible use of red mud for stabilizing clayey soil and in road construction has been explored by Kalkan [10] and Singh [11]. It is reported that, addition of red mud increased the strength and decreased the hydraulic conductivity of the soil.

Hierarchical cluster analysis is a tool to determine hierarchy of different clusters formed by different variables of the problem being studied. This tool can be effectively used to determine the hierarchical order of influence of the independent variables in affecting dependentvariable. Hierarchical cluster analysis is found reported to be used effectively in different disciplines [12, 13]. More studies pertaining to explore the possibility of using industrial wastes/by-products for stabilizing soil can be found in the literature [14-17].

While number of research studies is found to be reported [1-11, 14-17]with respect to exploring the possibilities of using industrial by-products/wastes in improving the engineering characteristics of the soil, it is noted that, studies pertaining to explore the possibilities of using combination of industrial by-products/wastes in highway construction are not found to be reported in the literature. This paper presents and discusses the results of the study carried out to explore the possibilities of using two or more industrial wastes/by-products for highway construction. The industrial by-products/wastes considered are WFS, fly ash and red mud. Cement and lime are used as stabilizing materials in this study. Samples with different percentages of WFS, fly ash and red mud were considered together with one of the stabilizing materials. The mixturesweretested to determine California Bearing Ratio (CBR). Theresults of the experimental studies are presented and discussed. The results of the experimental study was analyzed using hierarchical cluster analysis in MATLAB to determine the order of influence of the percentage of WFS, fly ash, red mud, cement and lime in affecting CBR.

Materials used

The WFS used in the present studyhasapproximately 99 percent particles that passed 2. 36 mm sieve. Coefficient of curvature and uniformity coefficient are determined to be 1. 16 and 2.52, respectively, and hence, as per Uniform Soil Classification system, WFS is classified as poorly graded. Effective size of WFS is found to be 0. 21mm. Chemical composition of the WFS determined using chemical analysis is given in Table 1. The silica content in WFS is found to be less compared to that reported by Guney et al. [4]. Physical observations indicated that, WFS had no significant cohesive properties.

TABLE.1. Chemical composition of WFS

Chemical compositionCompound	% value
Silica (as SiO_2)	93. 54
Alumina (as Al_2O_3)	1. 89
Calcium (as CaO)	0. 34
Magnesium (as MgO)	0. 10
Manganese (as MnO)	0. 019
Iron (as Fe_2O_3)	1. 03
Titanium (as TiO_2)	0. 17
Phosphorus (as P_2O_5)	0. 018
Potassium (as K_2O)	0. 064
Sodium (as Na_2O)	0. 12
Loss on ignition	2. 61

Fly ash was procured fromTuticorin thermal power plant and locally available red mud was used. Fineness modulus and specific gravity of the fly ash used are 0. 058 and 2.30, respectively.The chemical properties of the fly ash used in the present study are given in Table 2. The specific gravity of the fly ash and red mud is found to be 2. 05 and 1.75, respectively.Portland Pozzolana Cement of 53 grade and ordinary lime were used as stabilizing materials.

TABLE.2. Chemical properties of the fly ash used in the present study

Constituent (%)	Fly ash
Total silica (SiO2)	50. 40
Reactive silica	5. 61
Alumina (Al2O3)	18. 81
Ferric oxide (Fe2O3)	16. 61
Total calcium (CaO)	9. 00
Free lime	3. 92
Magnesium (MgO)	1. 41
Titanium(TiO2)	0. 28
Potassium (K2O)	3. 46
Sodium (Na2O)	0. 18
Loss on ignition	2. 60

Mixture proportions considered

Totally forty two samples are considered for the experimental study. WFS and fly ash form the major ingredient of the samples considered for the experimental study. Different mixture proportions are arrived by replacing WFS with different percentages of fly ash. One of the stabilizing materials such as cement and lime is added to the mix proportions considered. 5% of the stabilizing material is used. The percentages of red mud considered are 5 and 10. Table 3 gives the mixture proportions of the samples considered.

TABLE.3. Mixture proportions considered

ID	Industrial wastes/by-products			Stabilizing material	
	WFS	Fly ash	Red mud	Cement	Lime
S1	100	0	0	0	0
S2	95	0	0	5	0
S3	90	5	0	5	0
S4	85	10	0	5	0
S5	80	15	0	5	0
S6	75	20	0	5	0
S7	70	25	0	5	0
S8	65	30	0	5	0
S9	60	35	0	5	0
S10	55	40	0	5	0
S11	90	0	5	5	0
S12	85	5	5	5	0
S13	80	10	5	5	0
S14	75	15	5	5	0
S15	70	20	5	5	0
S16	65	25	5	5	0
S17	50	30	5	5	0
S18	55	35	5	5	0
S19	50	40	5	5	0
S20	85	0	10	5	0
S21	80	5	10	5	0

S22	75	10	10	5	0
S23	70	15	10	5	0
S24	65	20	10	5	0
S25	60	25	10	5	0
S26	55	30	10	5	0
S27	50	35	10	5	0
S28	45	40	10	5	0
S29	95	0	0	0	5
S30	90	5	0	0	5
S31	85	10	0	0	5
S32	80	15	0	0	5
S33	75	20	0	0	5
S34	70	25	0	0	5
S35	65	30	0	0	5
S36	60	35	0	0	5
S37	55	40	0	0	5
S38	90	0	5	0	5
S39	85	5	5	0	5
S40	80	10	5	0	5
S41	75	15	5	0	5
S42	70	20	5	0	5
S43	65	25	5	0	5
S44	60	30	5	0	5
S45	55	35	5	0	5
S46	50	40	5	0	5
S47	85	0	10	0	5
S48	80	5	10	0	5
S49	75	10	10	0	5
S50	70	15	10	0	5
S51	65	20	10	0	5
S52	60	25	10	0	5
S53	55	30	10	0	5
S54	50	35	10	0	5
S55	45	40	10	0	5

Experimental study

Experiments were carried out to determine the California Bearing Ratio (CBR) of all the samples considered. As suggested by Kelven [18], for CBR tests, WFS was hydrated for one week so as to ensure hydration of thermally degraded bentonite. For CBR tests, the mixture of industrial by-products/wastes were compacted under modified proctor effort and cured for 7 daysbefore testing. CBR test was carried out following the recommendations of ASTM D 1883-07.

Analytical study

Hierarchical cluster analysis is used to analyze the results of the experimental study. This can be used to analyze large quantity data to determine possible clusters and hence the results of the cluster analysis depend purely on the numeric values of the data being processed. In MATLAB, cluster analysis is performed using functions such as pdist, linkage and cluster. Pdist is the function that determines the Euclidean distance between the pair of objects. Using the Euclidean distance the objects those are at close proximity are linked together using linkage function. The resulting hierarchical cluster is linked to other object based on the Euclidean distance. This procedure is continued until all the objects considered are included to form one cluster. The hierarchical order of influence of one object on other objects can thus be determined once the bigger hierarchical cluster with all the considered objects is formed. The result of the linkage function is shown pictorially using 'dendrogram'. The dendrogram is a hierarchical cluster tree that pictorially represents the clusters formed and the Euclidean distance at which they are formed. A typical dendrogram is shown in Fig. 1.

It is observed from Fig. 1 that, the objects with object number 1 and 2 are linked to form the first cluster. The objects 3 and 4 are seen to form the second cluster. The clusters 1 and 2 thus formed are linked to form a bigger cluster 3. The procedure is continued until one big cluster is formed including all the objects considered for the cluster analysis. In this study, the hierarchical cluster analysis is used to determine the hierarchical order of influence of variables such as the percentage of WFS, fly ash, red mud, cement and lime in affecting the object CBR. The objects and the object number considered for hierarchical cluster analysis are given in Table 4.

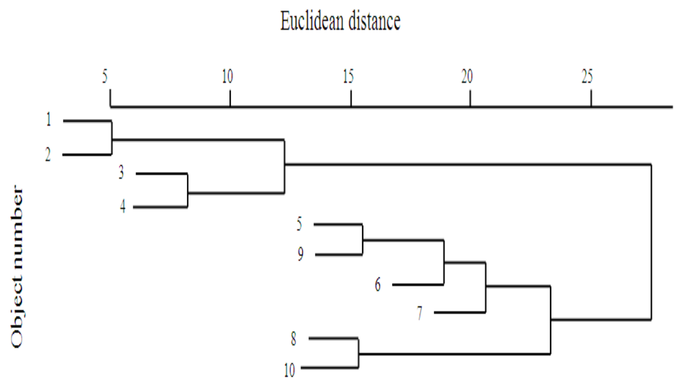

Fig. 1.Typical Dendrogram[19]

TABLE.4. Objects and object numbers used for cluster analysis

Object	WFS	Fly ash	Red mud	Cement	Lime	CBR
Object No.	1	2	3	4	5	6

Results and discussions

The results of the CBR tests carried out are given in Table 5 and are shown pictorially in Fig. 2. The Optimum Moisture Content (OMC) and the dry density (g/cc) of the samples considered are also given in Table 5.

TABLE.5. CBR value, OMC and Density of the samples tested

ID	**CBR (%)**	**OMC (%)s**	**Density (g/cc)**	**ID**	**CBR (%)**	**OMC (%)**	**Density (g/cc)**
S1	11	10.8	1.778	S29	28	11.4	1.798
S2	40	11.18	1.816	S30	35	11.58	1.875
S3	52	11.6	1.858	S31	42	12	1.885
S4	61	12	1.882	S32	48	12.4	1.889

S5	71	12.4	1.891	S33	51	12.8	1.898
S6	78	12.6	1.842	S34	52	13	1.871
S7	81	13	1.789	S35	49	14	1.795
S8	76	13.5	1.742	S36	43	14.8	1.735
S9	68	14	1.722	S37	34	15.2	1.710
S10	58	14.8	1.692	S38	26	11.6	1.829
S11	36	12	1.829	S39	35	12.8	1.840
S12	53	13.2	1.842	S40	43	13.4	1.864
S13	68	13.4	1.858	S41	51	13.8	1.893
S14	77	14	1.86	S42	56	14.0	1.884
S15	82	14.2	1.865	S43	54	14	1.825
S16	81	14.6	1.852	S44	50	14.4	1.734
S17	75	15	1.868	S45	44	15	1.718
S18	68	15.4	1.814	S46	36	15.2	1.650
S19	60	16	1.808	S47	21	12	1.815
S20	26	12	1.7910	S48	30	12.9	1.840
S21	48	12.4	1.824	S49	41	14	1.884
S22	64	12.8	1.885	S50	49	14.2	1.895
S23	72	13	1.918	S51	48	14.6	1.885
S24	70	14	1.891	S52	45	14.8	1.875
S25	63	14.8	1.818	S53	40	15	1.840
S26	54	15.2	1.785	S54	35	15.8	1.770
S27	43	15.8	1.735	S55	28	16	1.715
S28	30	16.2	1.710				

The CBR value of the sample which contains only WFS is found to be very low compared to all the samples considered. This is the fact that, WFS is classified to be poorly graded with no cohesion. Addition of fly ash, red mud and stabilizing material, in general, is found to have profound effect on the strength of the WFS to be used in road construction. The results of experimental study also indicate that, in general, irrespective of the amount of red mud considered in the present study, usage of cement as a stabilization material is seen to improve the strength of the WFS than using lime. This is expected because the cement hydration products is known to improve the bonding of the adhering particles and hence the strength. From the Fig. 2, it is observed that for samples without red mud and containing cement as the stabilizing material, addition of fly ash upto20% increases the strength of the WFS. Addition of fly ash more than 20% is seen to reduce the strength of the WFS significantly. Similar observations of strength reduction in concrete beyond certain percentage fly ash addition have also been reported [12]. The samples containing lime is observed to have less strength for all the percentages of fly ash considered.

It is also observed that, at 5% use of red mud, upto20% addition of fly ash increase in fly ash percentage increased the strength. The strength improvement is more when cement is used as the stabilizing material. The strength of the WFS reduced significantly when the fly ash percentage is more than 20%. For 5% use of red mud, the strength variation with different percentages of fly ash is found to followed similar trend for both the stabilizing materials considered.

For the samples containing 10% of red mud and containing both the stabilizing materials, upto 15% usage of fly ash, the strength increased with increase in fly ash percentage. Beyond 15% usageof fly ash, the strength reduced significantly. It is important to note that, for most of the samples considered, the CBR value is found to be more than the minimum required by IRC 37 to be used for the sub-base course.

The dendrogram obtained from the cluster analysis is shown in Fig. 3. It is observed from the Fig. 3 that, the object number 6 (CBR) is seen to affected predominantly by the object number 1 (WFS). Physically this may be interpreted as the percentage of WFS used in the sample is found to have predominant effect on the strength than the percentage of other ingredients. Next to WFS, the percentage of fly ash is seen to affect the strength by linking the object number 2 with the cluster formed by the object numbers 1 and 6. Next to fly ash, red mud is seen to link with the clusters formed by the object numbers 1, 6 and 2. The presence of the stabilizing materials cement and lime are found to have equal effect on the strength of the sample because the object numbers 4 and 5 are linked together to link with the clusters formed by the object numbers 1, 6, 2 and 3.

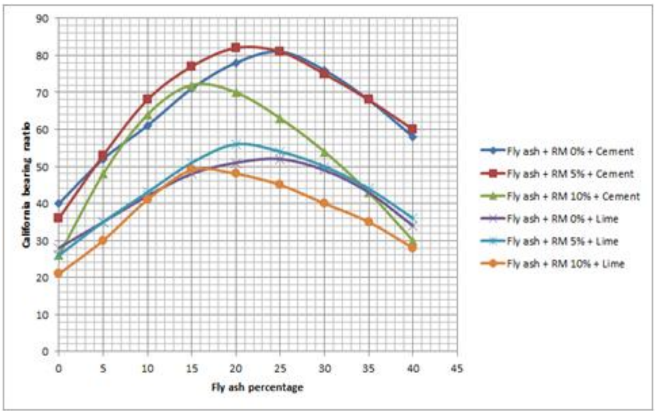

Fig. 2.Variation of CBR with different percentage of fly ash

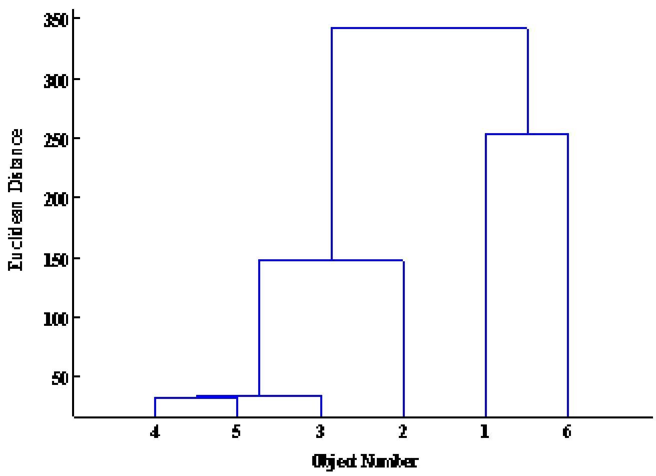

Fig. 3.Dendrogram obtained from cluster analysis

Summary and conclusions

Experiments were carried out to determine the possibilities of using combination of WFS, fly ash and red mud together with one of the stabilizing materials such as cement and lime for highway construction. Experiments to determine the CBR of the samples considered were carried out under modified proctor energy. The test results were analyzed and discussed. Hierarchical cluster analysis was used to analyze the experimental results using MATLAB. Based on the experimental and analytical study carried out and reported in this paper, following conclusions are drawn.

The percentage of WFS and fly ash is seen to play a major role in affecting the strength (CBR) of the sample. Use of cement as the stabilization material improves the strength than using lime. 20% percentage of fly ash, 5% use of red mud with 5% cement as the stabilization materialsfound to be the optimum mix proportion. It is also found that, most of the samples considered had CBR value greater than the minimum required by IRC 37 to be used as sub-bases course in highways. In general, it is concluded from the experimental and analytical study reported in this paper that, there is a promising future for using combination of industrial by-products/wastes for highway construction which would lead to attain sustainable development.

Acknowledgment

The authors thank all staffs of University College of Engineering who have helped directly or indirectly in carrying out the work.

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