An experimental study on the feasibility of using combination of industrial by-products and wastes as highway construction materials

S. Judes Sujatha¹, J. Sahaya Ruben², A.Sumil Kumaran³

¹Department of Civil Engineering, University College of Engineering, Nagercoil, Tamil Nadu, India, Pin: 629 004. E-mail: judessuja@yahoo.com, Tel.: +91 9442054675, Fax: +91 4652 260511.
²Department of Civil Engineering, Rohini College of Engineering and Technology, Kanyakumari-629 401, Tamil Nadu, India, E-mail: rubensjr1@gmail.com, Tel.: +91 9894176118.
³Department of Civil Engineering, EASA College of Engineering and Technology, Coimbatore -641105, Tamil Nadu, India, Tel: +91 7418865896.

*Corresponding Author

Abstract. Use of industrial by-products and wastes as highway construction materials help achieving sustainable development. This paper presents and discusses the results of the experimental studies carried out to determine the effect of combination of different industrial by-products and wastes on unconfined compressive strength variation of the mixtures. The effect of different stabilizing agents such as cement and lime, and the effect of different curing periods such as 7-days, 14-days and 28-days on the strength variation are also examined.

Keywords. Highway Materials, Waste Foundry Sand, Fly Ash, Red Mud, Sustainability, Environment

1. INTRODUCTION

In light of achieving sustainable development, use of industrial by-products and wastes for construction of highways and village roads may be considered to be one of the effective ways to reduce carbon footprint. Since road construction consumes large volumes of materials, there is wide scope for using large volumes of industrial by-products and wastes that are normally disposed of on vacant land thereby preventing or reducing adverse effects on the environment. There are different industrial by-products and wastes that may be considered for use as partial or full replacement of conventional highway construction materials. Some of them are waste foundry sand (WFS), fly ash (FA), red mud (RM), blast furnace slag and cement kiln dust. When the quantity of some of these industrial by-products and wastes are insufficient, possibility of using combination of these industrial by-products and wastes may be considered. Nevertheless, studies on the effect of using combined industrial by-products and wastes on geotechnical strength parameters have to be carried out in order to make a conclusive statement. It is also to be noted that, combination of different wastes materials may also help achieving reduced disposal of wastes from different types of industries.

Sen and Mishra (2010) reviewed the possibilities of using the industrial wastes such as waste foundry sand, phospogypsum, fly ash, blast furnace slag, waste plastic bags and colliery sand for the construction of village roads. They reported that, use of these materials improves the engineering properties of the soil. Schroeder (1994) had listed fifteen waste materials that have been used in the past or being used successively at present for highway or embankment constructions.

Sybilski (2004) done the investigations to determine the possibilities of using different industrial wastes for highway construction. The author suggests that new guidelines and recommendations must be developed so as to effectively use the industrial wastes and by-products for highway construction.

Kirk (1998) showed that waste foundry sand from ferrous industries can provide engineering properties that are suitable for construction of highway embankment. The geotechnical test results that arrived indicate the strength and deformation performance of WFS as a structural fill is comparable to that of made using natural sand. Nevertheless, it is was noted that WFS fill cannot be considered to be freely draining and WFS material did not result in toxicity higher than that one can expect from using...
the natural sand. The author also pointed out that lack of decision, based on the scientific tools such as life-cycle or risk-based analysis methods form the barricades to reuse WFS for beneficial purposes. Mast and Fox (1998) studied the use of industrial waste foundry sand as a highway embankment material by conducting the field demonstration. Geotechnical concerns such as strength, deformation and hydraulic conductivity were evaluated in the highway project.

Goodhue et al. (2001) have noted that to facilitate beneficial reuse of WFS, typical strength parameters of the soil should be available to the designers. Towards providing the required design parameters, they have conducted the testing to characterize the strength of WFS and their interaction with geosynthetics. Tests such as multistage interface shear tests, direct shear tests, and pull-out tests were carried out in their study. The results of the tests indicate that WFS can be used in geotechnical construction effectively. Guney et al. (2006) have carried out laboratory experiments on soil-WFS mixtures to test their strength parameters and hence the suitability of the mixture to use as highway sub base materials. Cement and lime were used in their study as stabilization materials. The considered mixture proportions were compacted at different moisture contents and tests such as unconfined compression (UCS), California bearing ratio (CBR) and hydraulic conductivity tests were carried out.

Kalkan (2006) has carried out a study to determine the suitability of using red mud for soil stabilization. They report, that clay samples in compacted state containing red mud and cement–red mud additives have compressive strength higher than other soil samples.

The effect of combination of different industrial by-products or wastes is not found reported in the literature. There is an urgent to explore the effect of using combination of industrial by-products and wastes on the geotechnical strength parameter.

In this research, experimental studies were conducted out to determine the possible use of combination of different industrial by-products or wastes such as foundry sand, fly ash and red mud as highway and village road construction materials. Two types of stabilizing agents, cement and lime are considered in this study. Unconfined compressive strength (UCS) of soil mixtures having different percentages of industrial by-products and wastes were determined at three different curing periods such as 7, 14 and 28 days.

2. MATERIALS AND METHODOLOGY

The materials used in the present experimental study and the methodology adopted was discussed in this section. Waste foundry sand (WFS) was obtained from the nearby foundry industry, fly ash and red mud were obtained from aluminium industry and thermal power plant. WFS approximately had 99% particles that passed 2.36mm sieve. Physical observations indicated that, WFS had no significant cohesive properties. From particle size distribution, the coefficient of curvature and uniformity coefficient were determined to be 1.16 and 2.52, respectively. Thus the WFS used in the presented study is classified as per Uniform Soil Classification system as poorly graded. Effective size of WFS is found to be 0.21mm. Table 1 gives the chemical composite of the WFS.

| Sl. No. | Compound            | %    |
|--------|---------------------|------|
| 1      | Silica (as SiO₂)    | 93.54|
| 2      | Alumina (as Al₂O₃) | 1.89 |
| 3      | Calcium Oxide (CaO) | 0.34 |
| 4      | Magnesium Oxide (MgO) | 0.10 |
| 5      | Manganese (as MnO)  | 0.019|
| 6      | Iron (as Fe₂O₃)    | 1.03 |
| 7      | Titanium (as TiO₂)  | 0.17 |
| 8      | Phosphorus (as P₂O₅) | 0.018|
Potassium (as K₂O) 0.064
Sodium (as Na₂O) 0.12
Loss on ignition 2.61

Class F fly ash was used in this study. Fineness modulus of the fly ash is 0.058 and the specific gravity is 2.3.
The red mud used was obtained from Aluminium industry named M/S Malco located at Salem, Tamilnadu, India. Chemical composition of fly ash and red mud used were studied.
The cement used is Ordinary Portland Cement of 53 Grade conforming to the IS 12269 (1987). The lime used was obtained by heating and grinding seashells. The seashells were obtained from Kanyakumari district, TamilNadu, India. Mixture proportions considered for this experimental investigation are given in Table 2.

| ID | WFS | Fly Ash | Red mud | Cement | Lime |
|----|-----|---------|---------|--------|------|
| UC1 | 85 | 10 | 0 | 5 | 0 |
| UC2 | 80 | 15 | 0 | 5 | 0 |
| UC3 | 75 | 20 | 0 | 5 | 0 |
| UC4 | 70 | 25 | 0 | 5 | 0 |
| UC5 | 65 | 30 | 0 | 5 | 0 |
| UC6 | 60 | 35 | 0 | 5 | 0 |
| UC7 | 85 | 5 | 5 | 5 | 0 |
| UC8 | 80 | 10 | 5 | 5 | 0 |
| UC9 | 75 | 15 | 5 | 5 | 0 |
| UC10 | 70 | 20 | 5 | 5 | 0 |
| UC11 | 65 | 25 | 5 | 5 | 0 |
| UC12 | 60 | 30 | 5 | 5 | 0 |
| UC13 | 85 | 0 | 10 | 5 | 0 |
| UC14 | 80 | 10 | 10 | 5 | 0 |
| UC15 | 75 | 15 | 10 | 5 | 0 |
| UC16 | 70 | 20 | 10 | 5 | 0 |
| UC17 | 65 | 25 | 10 | 5 | 0 |
| UC18 | 60 | 30 | 10 | 5 | 0 |
| UC19 | 85 | 10 | 0 | 0 | 5 |
| UC20 | 80 | 15 | 0 | 0 | 5 |
| UC21 | 75 | 20 | 0 | 0 | 5 |
| UC22 | 70 | 25 | 0 | 0 | 5 |
| UC23 | 65 | 30 | 0 | 0 | 5 |
| UC24 | 60 | 35 | 5 | 0 | 5 |
| UC25 | 85 | 0 | 5 | 0 | 5 |
Optimum Moisture Content (OMC) and the corresponding dry unit weight of the mix proportions were determined using the guidelines of ASTM D1557-12e1. Unconfined compressive strength (UCS) is determined by using the guidelines of ASTM D1633-07. The mix proportions of industrial wastes and by-products considered are compacted at OMC. The compacted samples are wrapped and cured for 7-day, 14-days and 28-days.

3. RESULTS AND DISCUSSION

The results of the experiments are given in Table 3.

Table 3. UCS Test Results of Mixtures Considered

| ID  | UC26 | UC27 | UC28 | UC29 | UC30 | UC31 | UC32 | UC33 | UC34 | UC35 | UC36 |
|-----|------|------|------|------|------|------|------|------|------|------|------|
| OMC | 80   | 80   | 80   | 80   | 80   | 80   | 80   | 80   | 80   | 80   | 80   |
| Wt  | 10   | 15   | 20   | 25   | 30   | 85   | 5    | 75   | 70   | 65   | 60   |
| Wt  | 5    | 5    | 5    | 10   | 10   | 0    | 10   | 10   | 15   | 20   | 25   |
| Wt  | 0    | 0    | 0    | 0    | 0    | 10   | 0    | 0    | 10   | 10   | 10   |
| Wt  | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    | 5    |

| UC26 | 107 | 302 | 427 |
| UC27 | 213 | 444 | 551 |
| UC28 | 320 | 658 | 729 |
| UC29 | 462 | 784 | 889 |
| UC30 | 384 | 640 | 711 |
| UC31 | 320 | 534 | 604 |
| UC32 | 622 | 960 | 1134|
| UC33 | 498 | 782 | 960 |
| UC34 | 462 | 676 | 853 |
| UC35 | 178 | 498 | 711 |
| UC36 | 284 | 711 | 889 |
| UC37 | 424 | 960 | 1134|
| UC38 | 551 | 1067| 1244|
| UC39 | 452 | 853 | 1089|
| UC40 | 419 | 747 | 995 |
| UC41 | 76  | 107 | 121 |
3.1 Cement as Stabilizing Agent

With cement as stabilizing agent, effect of use of different percentages of red mud, fly ash and different curing periods on the strength variation is discussed in this section. Fig. 1 shows strength variation with different percentages of red mud.

![Graph showing strength variation with red mud percentage](image1)

**Figure 1. Strength Variation with Red Mud Percentage**

From the Fig. 1, it is observed that, the strength increases with increase in the WFS percentage up to 70% beyond which the strength reduces. This may be attributed to reduction in the finer particles.
in the mixtures that actually form the matrix to hold the relatively coarser particles of WFS. This observation is in general seen for all three curing periods considered. Comparing the curves at different curing period indicates that rate of decrease in the strength is relatively lower for the mixtures which is cured for 28-days than the specimens cured for 7 and 14-days. The effect of the different curing periods in strength may be inferred from Fig. 2.

![Figure 2. Strength Variation with Curing Period](image)

Fig. 2 it is seen that in general strength increases when curing period is increased. Red mud corresponding to 0%, 5% and 10% with different percentage of fly ash were studied. Fig. 3 indicates that use of 5% red mud corresponds to different amount of fly ash in the mixture.

![Figure 3. Effect of Fly Ash Percentage on Strength](image)

More than 20 per cent use of fly ash was found to reduce the strength of the mixture. Hence this percentage was considered as optimum.

3.2 Lime as Stabilizing Agent
With lime as stabilizing agent, effect of use of different percentages of red mud, fly ash and different curing periods on the strength variation is discussed in this section. Fig. 4 shows the strength variation with different percentages of red mud used.

![Figure 4. Strength Variation with Red Mud Percentage](image)

Fig. 4 indicates that use of 5% red mud resulted in higher strength compared to 10% use of red mud. Nevertheless, with respect to cement as stabilizing agent, 5% use of red mud resulted in higher strength. Thus, there seems to be chemical reactions between red mud and cement compounds or compounds formed during hydration. With lime, red mud is less effective under higher per cent of its usage. But with cement, use of higher per cent of red mud increased the strength. From fig.5 the effect of curing periods over the strength can be inferred.

Fig. 5, indicates in general the strength of mixtures increase with the increase in curing period. It is also noted that, the strength corresponding to 14-days of curing is nearly the same as that of 28-days curing.
The effect of use of fly ash in the mixture and the strength at different curing periods was inferred. Based on the result it was found that more than 20% use of fly ash reduces the strength of the mixture same as cement as a stabilising agent.

4. Summary and Conclusions

The experimental study which was carried out to investigate the strength parameter of industrial by-products and wastes such as fly ash, waste foundry sand (WFS) and red mud together with stabilizing agent such as cement and lime were discussed and summarised below.

- Strength of the mixture decreases when WFS percentage was increased beyond 70% and hence 70% of WFS may be considered to be optimum.
- For both stabilizing agents considered in this study, in general it is found that strength of mixtures increases with increase in the curing period.
- When lime is used as stabilizing agent, red mud is found to be less effectual in improving the strength.
- 20% use of fly ash in the mixture may be considered to be an optimum content.
- Use of combined use of industrial by-products and wastes may thus be considered a viable option of disposing them in large quantities. More importantly this technology would ultimately help achieving sustainable development.

REFERENCES

1. Dhawan, PK, Swami, RK, Mehta, HS, Bhatnagar, OP & Murty, AVRS, 1994, Bulk utilization of coal ashes from road works, Indian highways, 22 11 21-30.
2. Sen, T & Mishra, U 2010 Use of Industrial Waste Products in Village Road Construction International Journal of Environmental Science and Development 1 2.
3. Schroeder, RL 1994 The use of recycled materials in highway construction Public Roads 57 32-41.
4. Sybilski 2004 Use of Industrial Waste Materials in Road Construction in Poland International RILEM Conference on the Use of Recycled Materials in Building and Structures. RILEM Publications SARL 351-360.
5. Kirk, PB 1998 Field Demonstration of Highway Embankment Constructed Using Waste Foundry Sand, Ph.D. Dissertation, Purdue University, West Lafayette, IN, 202 p.
6. Mast, DG & Fox, PJ 1998 Geotechnical performance of a highway embankment constructed using waste foundry sand. In: Vipulanandan, C., Elton, D. (Eds.), Recycled Materials in Geotechnical Applications, Geotechnical Special Publication 79. ASCE, Boston, MA, pp. 66-85.
7. Goodhue, M, Edil, TB & Benson, CH 2001 Interaction of foundry sand with geosynthetics Journal of Geotechnical and Geoenvironmental Engineering 127 353-362.
8. Guney, Y, Aydilek, AH & Demirkan, MM 2006 Geoenvironmental behavior of foundry sand amended mixtures for highway sub-bases Waste management 26 9 932–945.
9. Prabakar, J, Dendorkar, N & Morchale RK 2004 Influence of fly ash on strength behavior of typical soils Construction and Building Materials 18 263-267.
10. Kalkan, E 2006 Utilization of red mud as a stabilization material for the preparation of clay liners Engineering Geology 87 220-229.
11. Mazloom, M, Ramezaniianpour, AA and Brooks, JJ 2004 Effect of silica fume on mechanical properties of high-strength concrete Cement and Concrete Composites 26 347-357.
12. Meenakshi, SS & Ilangovan, R 2011 Performance of Copper slag and ferrous slag as partial replacement of sand in Concrete International Journal of Civil and Structural Engineering 1 918-927.
13. Nath, P & Sarker, P 2011 Effect of Fly ash on the Durability Properties of High Strength Concrete Procedia Engineering 14 1149-1156.
14. Oner, A, Akyuz, S & Yildiz, R 2005 An experimental study on strength development of concrete containing fly ash and optimum usage of fly ash in concrete Cement and Concrete Research 35 1165-1171.
15. Rahal, K 2007 Mechanical properties of concrete with recycled coarse aggregate Building Environment 42 407-415.