Journal of Civil Engineering (IEB), 46 (1) (2018) 83-96

Journal of
Civil Engineering
IEB

# Geotechnical characterization of flyash-redmud mix stabilized with marble dust

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Received 21 February 2018

**Abstract**

The paper presents the geotechnical characterization of flyash-redmud mix stabilised with marble dust. Compaction tests were carried out on flyash-redmud and flyash-redmud-marble dust mixes. The results of this study reveal that the maximum dry unit weight increases with the increase in percentage of red mud in the flyash. The optimum moisture content decreased with the increase in the content of redmud up to 20 % in flyash. Beyond a content of 20 % of redmud in flyash, the optimum moisture content increases. A mix containing 30 % flyash and 70 % redmud was identified and used for studying the compaction behaviour by varying the content of marble dust. The maximum dry unit weight of the mix increased up to a marble dust content of 8%. Beyond a marble dust content of 8 %, the dry unit weight decreased. A reference mix containing 30 % flyash, 70 % redmud and 8 % marble dust was identified and used for studying the unconfined compressive strength, split tensile strength, bearing ratio, unconsolidated undrained triaxial behaviour, durability of the cured specimens. The curing period was varied from 7 to 90 days. The results reveal that unconfined compressive strength, split tensile strength, bearing ratio and deviator stress of the reference mix increased with the increase in curing period. The durability of the reference mix improved after the wetting and drying cycles. The trend is same at all curing period. The improved behaviour of the flyash-redmud-marble dust mix will boost the construction of sub grade in roads. Further, its use will also provide environmental motivation for providing a means of consuming large quantities of flyash, redmud and marble dust.



*Keywords:* Fly ash, red mud, marble dust, compaction, unconfined compressive strength, bearing ratio, deviator stress, durability, split tensile strength, EDAX, FESEM.

## 1. Introduction

Consequent upon growth of population, increasing production, urbanization and improved living standards there is increase in types and amounts of solid wastes generated by industrial, mining, domestic and agriculture activities. India produces around 960 million tons of solid wastes which pose a major environment and ecological problem. India has a total installed capacity of 100,000 MW of electricity generation. Seventy-three percent of this is based on thermal power generation. Electricity production from coal based thermal power plants are major source of fly ash production. For the total installed capacity of 80548 MW, the country's total coal demand in 2010-12 was 730 Mt. The forecast estimates the increase in coal demand by the year 2031-32 is approximately 2000 Mt. Indian fly ashes have high ash content varying from 30 to 50%. On the other hand, enormous quantity (2 million tons) of red mud is being generated in India posing a serious threat to the environment.

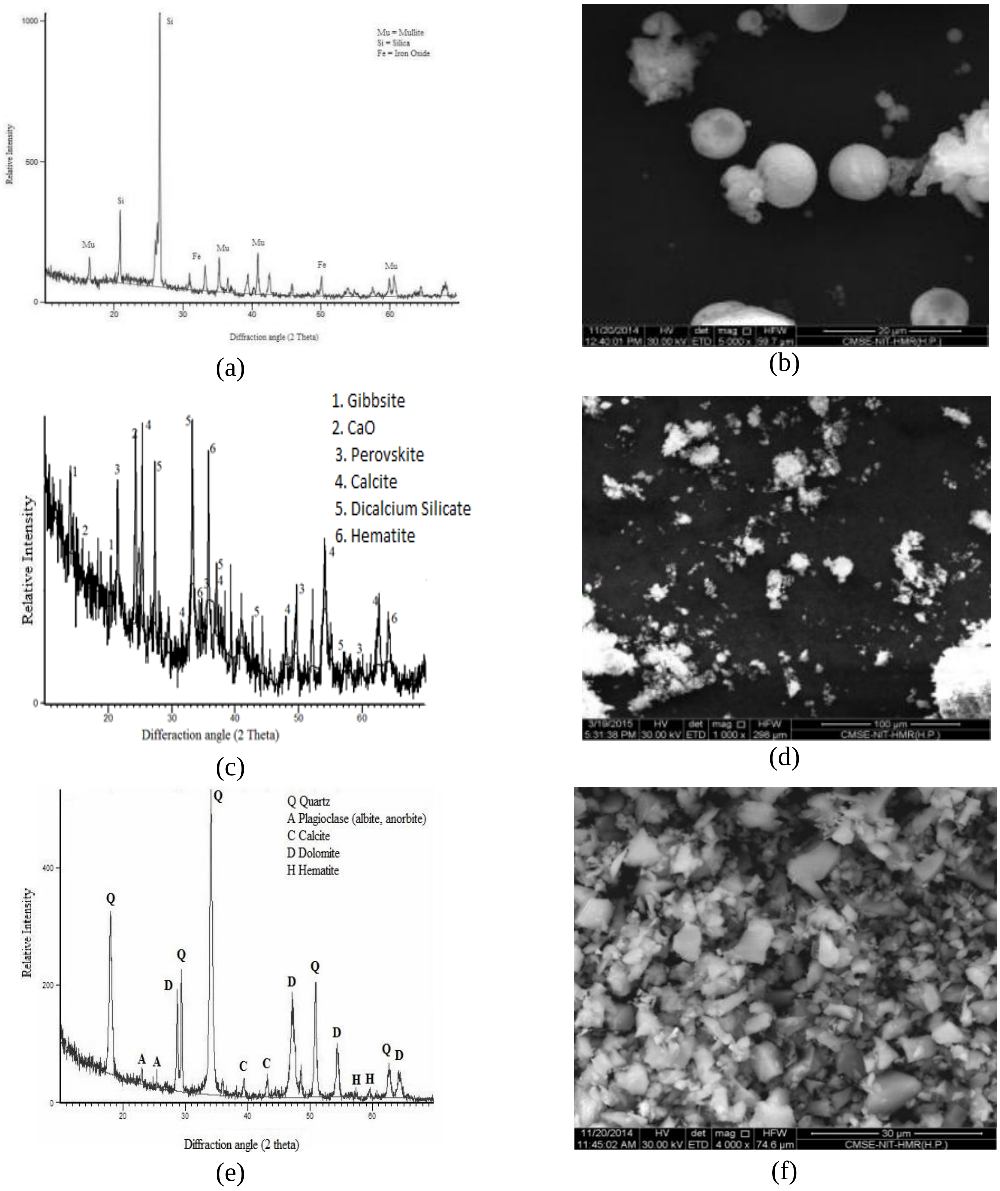



Fig. 1. (a) X.R.D of flyash, (b) SEM of fly ash (30kV, X5000, 20µm), (c) X.R.D of redmud (d) SEM of redmud (30KV, X1000, 100µm), (e) X.R.D of marble dust, (f) SEM of marble dust(30kV, X4000, 74.6µ).

Marble dust is another waste resulting from the quarrying and crushing of marble and India is among the top world exporters of marble stone. The Indian marble industry has been growing steadily at an annual rate of around 10% per year and 20 to 30% of marble blocks are converted in to powder. There are around 4000 marble mines and about 1100 marble cutters in medium sector spread over 16 districts of Rajasthan. Out of the total waste generated in India, contribution from Rajasthan state itself is 95% of the total accounting to 6 million tons annually. A viable solution of the problem can be is to mix them together and use them for some engineering application. This paper presents the geotechnical characterisation of flyash-redmud-marble dust mixes. A series of laboratory tests were carried out by varying the marble dust content and curing period. The results obtained from these tests are presented and discussed in this paper for possible application in civil engineering.

## 2. Background

Several studies have been reported on flyash such as geotechnical properties (Kaniraj and Havanagi 1999; Pandian 2004; Kumar *et al.* 2014), its use in soil stabilisation (Lo and Wardani 2002; Singh and Garg 2007; Satyanarayana *et al.* 2012), its use in roads and embankments (Ghosh and Subbarao 2006; Jadhao and Nagarnaik 2008), in coastal land reclamation (Kim and Chun 1994). Investigations were also carried out on the binding effect of lime, gypsum and its type on the strength development, pozzolanic reaction rate, and chemistry of lime-pozzolan cement (Fraay *et al.* 1990; Ghosh and Subbarao 1998; Ghosh and Subbarao 2001; Mishra and Karanam 2006). Properties/characteristics of fly ash individually or in combination with lime or cement or gypsum or phosphogypsum or in their different combinations available in literature were compaction (Consoli *et al.* 2001; Sivapullaiah and Moghal 2011; Mishra 2012), bearing ratio (Ghosh and Subbarao 2006; Jadhao and Nagarnaik 2008; Behera and Mishra 2012; Zhang and Xing 2002; Kolias *et al.* 2005; Ghosh 2010), durability studies (Fraay *et al.* 1990; Walker 1995; Dempsey and Thompson 1973; Garg *et al.* 1996; Gamble 1971), split tensile strength (Satyanarayana *et al.* 2012; Ghosh and Subbarao 2006; Fraay *et al.* 1990; Behera and Mishra 2012; Reddy and Gupta 2005), flexural strength (Walker 1995; Reddy and Gupta 2005; Bhattacharjee and Bandyopadhyay 2011), shear strength (Fraay *et al.* 1990; Consoli *et al.* 2001; Sivapullaiah and Moghal 2011; Walker 1995; Reddy and Gupta 2005; Ghosh and Subbarao 2007), unconfined compressive strength (Behera and Mishra 2012; Paya *et al.* 1999), XRD studies (Ghosh and Subbarao 2001; Shi 1996; Chatterjee 2001; Kaniraj and Gayathri 2003; Kaniraj and Gayathri 2004), and SEM studies (Ghosh and Subbarao 2001; Mishra and Karanam 2006; Shi 1996; Chatterjee 2001; Kaniraj and Gayathri 2003; Das and Yudbhir 2005; Joshi and Lothia 1997).

Table 1
Chemical composition of redmud, flyash and marble dust

| Chemical composition | Redmud | Flyash | Marble dust |
|---|---|---|---|
| Ferric Oxide ($Fe_2O_3$) (%) | 33.1 | 3.7 | 0.33 |
| Aluminum Oxide ($Al_20_3$) (%) | 18.2 | 37.80 | 0.70 |
| Silicon Dioxide ($SiO_2$) (%) | 8.8 | 45.60 | - |
| Calcium Oxide (CaO) (%) | 2.7 | 5.35 | 51.49 |
| Titanium dioxide ($TiO_2$) (%) | 19.6 | - | - |
| Sodium oxide ($Na_2O$)(%) | 5.8 | - | 0.19 |
| Sulfur trioxide ($SO_3$) (%) | - | - | 0.10 |
| Magnesium oxide (MgO) (%) | - | - | 0.36 |
| Potassium oxide ($K_2O$) (%) | | | 0.25 |
| Loss of ignition (%) | - | 4.52 | 44.60 |

Further, researchers have carried out various studies on redmud such as its use as pozzolan for Portland cement (Ribeiro *et al.* 2011), lime stabilized red mud mix in road construction (Satyanarayana *et al.* 2012), absorption properties of red mud towards phosphate removal from solutions (Yousif *et al.* 2012), geopolymerization of bauxite residue with acidic flyash (He and Zhang 2011), effect of additives on compressive strength of slag based inorganic polymers like kaolinite, pozzolan, flyash, redmud or calcium oxide (Zaharki and Komnitsas 2009), flexural strength of epoxy polymer concrete with red mud and flyash (Kumar *et al.* 2013).The potential of marble dust to stabilise red tropical soils for road construction was reported by (Okagbue and Onyeobi 1999). Reuse of marble dust as fine aggregate in ultra-high performance concrete was reported by (Sharma *et al.* 2013).The improvement in characteristics of expansive soil by using quarry waste and its comparison with other materials like cement and lime was reported by (Mishra and Mishra 2015). From the literature presented above, it is concluded that no study has been carried out on flyash-redmud mix mixed with marble dust. The paper presents the geotechnical characterization of flyash-redmud mix mixed with marble dust for its possible application to the civil engineering.

## 3. Materials used and experimental procedure

The flyash, redmud and marble dust used in the study was procured from Ropar Thermal Power Plant, Punjab, India, Hindalko Industries Limited at Renukoot India, and Makrana marble mines Naugaun (Kishangarh marble Industries), Rajasthan respectively. Chemical composition of these waste materials is shown in Table 1. Study of Table 1 reveals that the flyash contains high percentage of alumina and silica whereas marble dust contains high content of calcium oxide. The redmud is rich in iron content followed by titanium oxide and alumina.

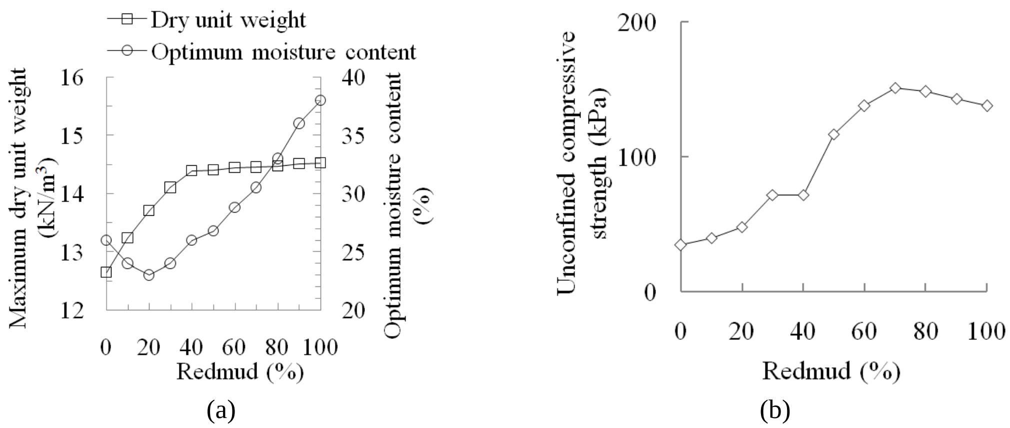



Fig. 2. (a) Variation of moisture content and maximum dry unit weight with varying percentage of redmud (b) Variation of unconfined compressive strength with percentage of redmud.

The specific gravity of flyash, redmud and marble dust used in this investigation were 1.90, 2.67 and 2.57 respectively. The maximum dry unit weight and optimum water content as obtained by standard proctor test for the flyash and redmud were 12.65 kN/m$^3$& 26 %and 14.52 kN/m$^3$& 38 % respectively. The scanning electron micrograph (SEM) and X-ray diffractogram (XRD) of fly ash, redmud and marble dust are shown in Figures.1 (a) & (b), Figures. 1 (c) & (d) and Figures 1 (e) & (f) respectively. Figure 1(a) shows the presence of mullite, silica, iron oxide. Figure. 1(b) shows solid spheres with some irregular shape particles as well. Figure. 1(c) indicates prominent peaks of gibbsite and calcium oxide along with few peaks of hematite. Figure. 1(d) shows that the arrangement of the particles is relatively loose, small and poorly crystallized with high porosity. Figure 1(e) shows the presence of indicates mostly quartz and dolomite peaks and few calcite peaks whereas Figure. 1(f) shows that the marble dust particles are irregular in shape. The specimens were cured using a sponge method of curing as the specimen gets dissolved in water. Compaction, unconfined compressive strength, split tensile strength, bearing ratio, unconsolidated undrained triaxial and durability tests were conducted in accordance with relevant Indian standards. The failed specimens obtained from the unconfined compressive strength tests were used for the energy dispersive x-ray spectroscopy and field emission scanned electron microscopy study. For easy reference and identification of specimen, specific codification was used. For example, the codification FA60RM40MD04 will indicate a mix containing 60% flyash, 40% redmud and 4 % marble dust.

## 4. Results

### *4.1 Compaction*

Compaction tests on the mixes of flyash and redmud were carried out. The results are shown in Figure 2 (a) showing the variation of the optimum moisture content and maximum dry unit weight.

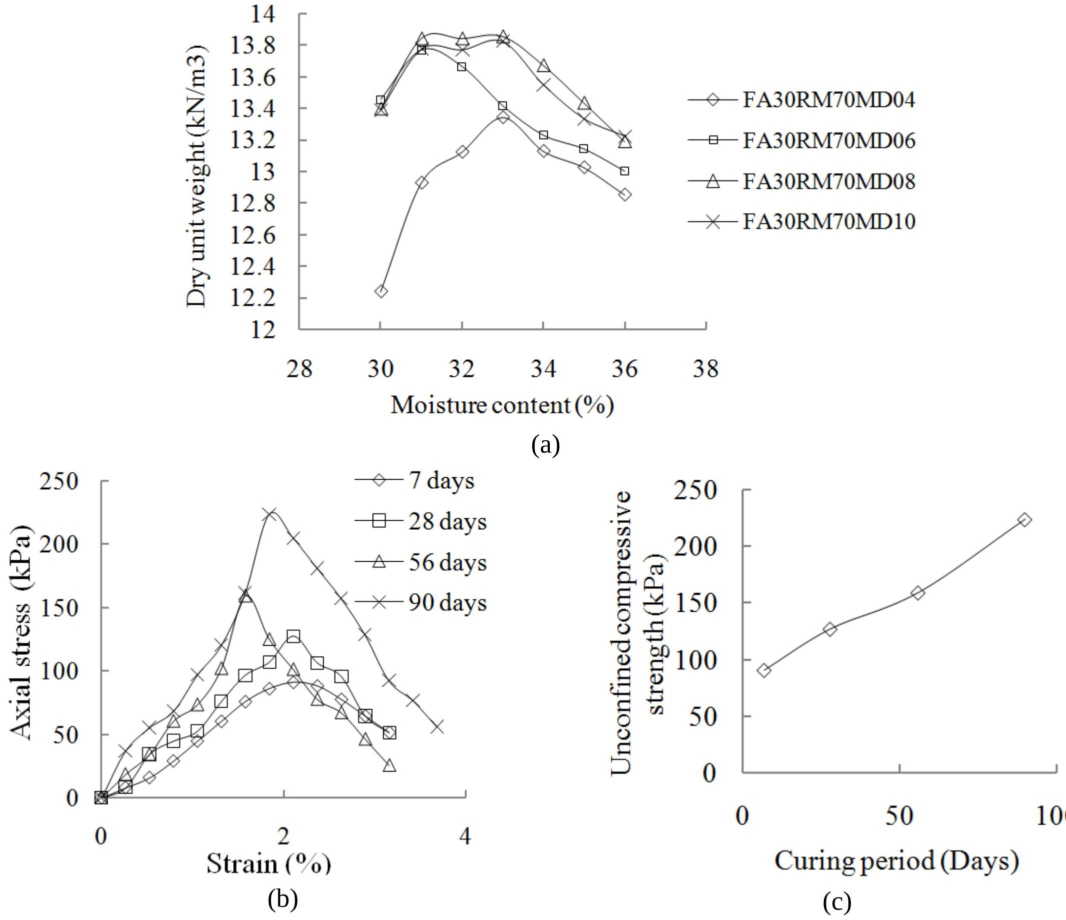



Fig. 3. (a) Compaction curves for the mix FA30RM70MD08 (b) Axial stress- strain curve for the mix FA30RM70MD08with curing period (c)Variation of unconfined compressive strength for the reference mix with curing period.

Study of Figure 2(a) reveals that the optimum moisture content decreased with the increase in the content of redmud up to 20 % in flyash. The decrease in the optimum moisture content is attributed to the dominance of flyash particles having lesser surface area and requiring less water to facilitate compaction in the flyash-redmud mix up to redmud content of 20 %. Beyond a content of 20 % of redmud in flyash, the optimum moisture content increases. This increase in the optimum moisture content is attributed to the presence of increasing amount of fines (redmud having larger surface area) in the composite requiring more water for lubrication due to increased surface area. Study of Figure 2(a) further reveals that the maximum dry unit weight increases with the increase in percentage of red mud in the flyash. This increase in the dry unit weight is attributed to the higher specific gravity of the redmud in comparison to the flyash in the mix. In order to decide the optimum mix of the flyash and redmud, it was decided to conduct unconfined compressive strength tests. The variation of unconfined compressive strength with variation of redmud in flyash is shown in Figure 2(b). This Figure reveals that the axial stress of the mix FA100RM00 was 34.45 kPa which increased to 151.04 kPa for the mix FA30RM70. This increase in axial stress with the addition of redmud to flyash is attributed to the improved gradation of the mix resulting increase in dry unit weight. Beyond a redmud content of 70 % in flyash, the axial stress decreased. This decrease in the axial stress is attributed to the poor gradation of the mix beyond a redmud content of 70 %. Therefore, a mix FA30RM70 was chosen for further studies.

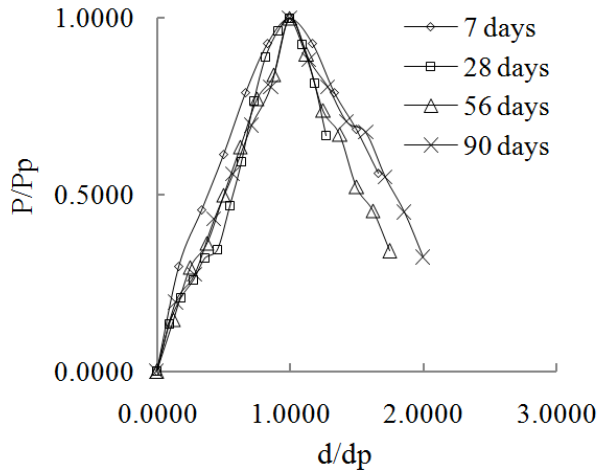



Fig. 4. Normalized stress-strain curve for the reference mix FA30RM70MD08 at different curing.

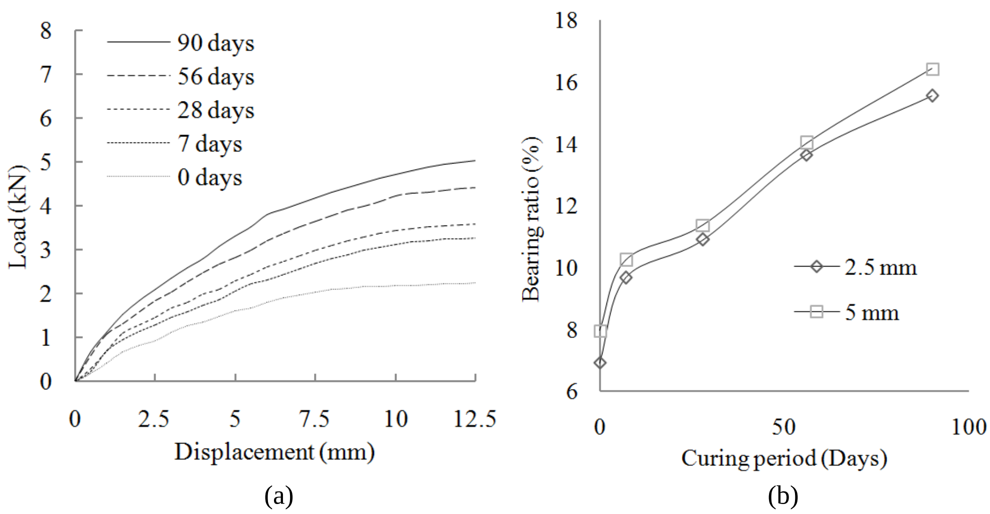



Fig. 5. (a) Load-displacement curves for the reference mix with cuing period, (b) Variation of bearing ratio for the reference mix with curing period.

The compaction curves for the mix FA30RM70 with varying content of marble dust are shown in Figure 3(a). Figure 3(a) reveals that the maximum dry unit weight of the mix FA30RM70 increased up to a marble dust content of 8 %. This increase in the dry unit weight is attributed to the improved gradation of the mix FA30RM70MD08 resulting increase in dry unit weight. Beyond a marble dust content of 8%, the dry unit weight decreased. The decrease in dry unit weight is attributed to the fact that calcium present in the marble dust reacts quickly with flyash-redmud mix resulting Base Exchange aggregation and flocculation which leads to increase in void ratio of the mix. This results in the decrease in the dry unit weight of the flyash-redmud mix. Further, study of this Figure reveals that the optimum moisture content increased with addition of marble dust to the mix FA30RM70. This increase in optimum moisture content is attributed to the fact that additional water held within the flocs resulting from flocculation due to calcium present in the marble dust. Based upon the compaction studies reported above, a reference mix FA30RM70MD08 was selected for the further experimental work.

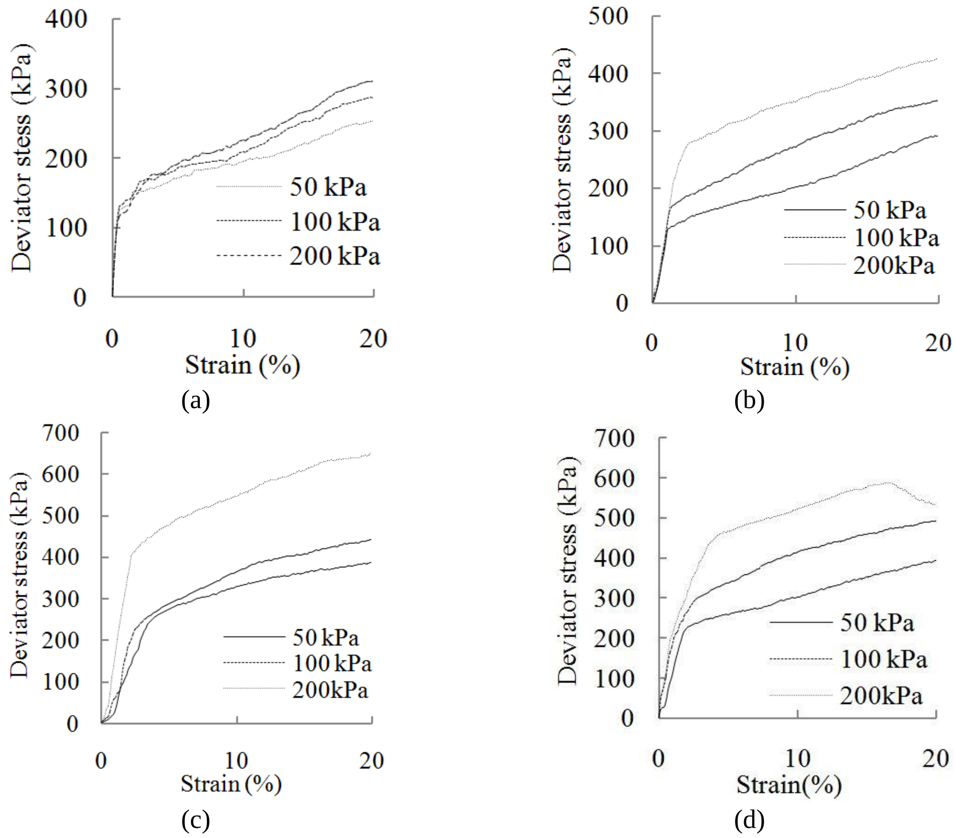



Fig. 6. Variation of deviator stress-axial strain for the reference mix at different confining pressures and at curing period of (a) 7 days (b) 28 days (c) 56 days and (d) 90 days.

*4.2 Unconfined compressive strength*

The axial stress strain curves for the reference mix FA30RM70MD08 and cured for 7, 28, 56 and 90 days are shown in Figure 3(b) and the variation of the unconfined compressive strength with the curing period is shown in Figure 3(c). The study of Figures 3(b) and 3(c) reveal that the unconfined compressive strength increased significantly with the increase in curing period. For example, the unconfined compressive strength of the reference mix at 7 days of curing was 90.79 kPa which increased to 127.11 kPa, 159.09 kPa and 223.69 kPa for 28, 56 and 90 days of curing respectively. The percentage increase in unconfined compressive strength for samples cured for28 days was about 40%, 75% and 146% respectively with respect to strength at 7 days.

The increase in unconfined compressive strength with the curing period is perhaps attributed to the pozzolanic reaction of marble dust with flyash-redmud mix resulting increase in the unconfined compressive strength. In order to study the post-peak behaviour, the stress axis of the axial stress-strain curve was normalized with respect to the peak axial stress, and the strain axis was normalized with respect to strain at the peak axial stress. The normalized stress-strain curve for the reference mix FA30RM70MD08 at a curing period of 7, 28, 56 and 90 days is shown in Figure 4. Study of Figure 4 reveals that the post failure behaviour is ductile. The ductile behaviour decreases with the increase in curing period. This may be attributed to the enhanced cementation due to formation of pozzolanic products decreasing the post failure ductile behaviour.

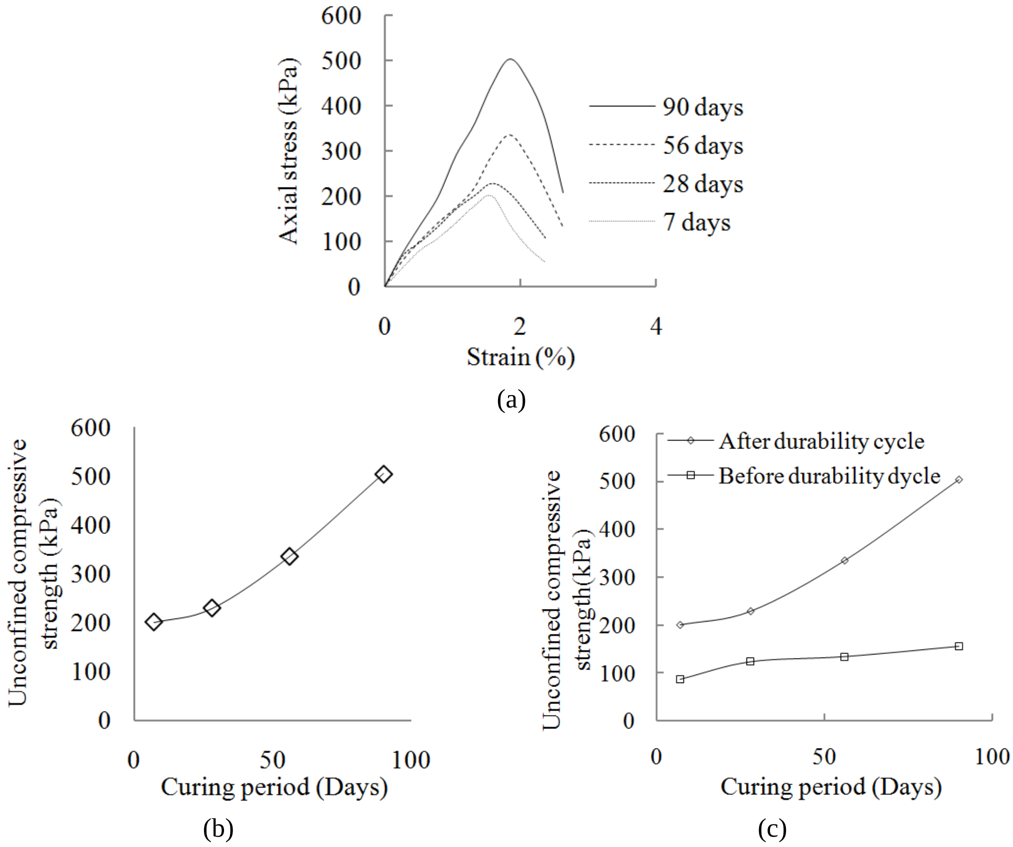



Fig. 7. (a) Axial stress-strain curves for the reference mix at different curing periods after the durability cycles (b) Variation of unconfined compressive strength after the durability cycles of the reference mix with curing period (c) Comparison of the unconfined compressive strength before and after the durability cycles.

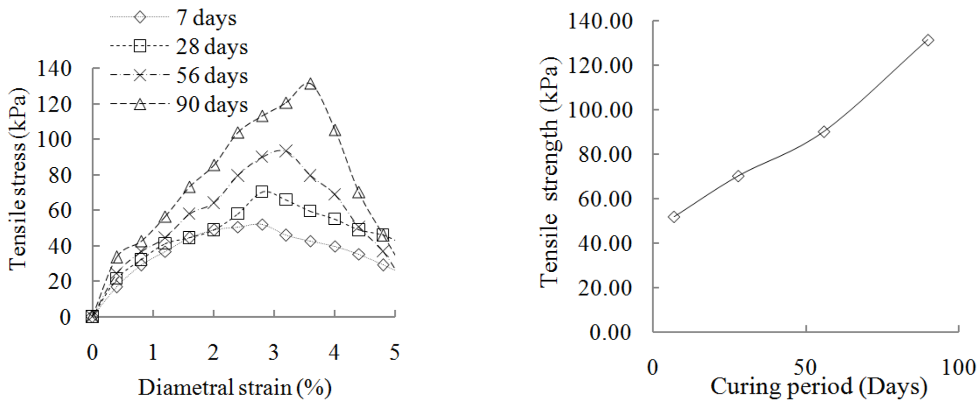
### *4.3 California bearing ratio*

The load-displacement behaviour of the reference mixes FA30RM70MD08 and cured for 7, 28, 56 and 90 days is shown in Figure 5(a). The variation of bearing ratio at a displacement of 2.5 mm and 5 mm respectively are shown in Table 2.

Study of Figure 5(a) and Table 2 reveal that the bearing ratio of the reference mix at 0 days of curing corresponding to a displacement of 2.5 mm was 6.93 % which increased to 9.68 %,10.91 %, 13.66 % and 15.56% for 7, 28, 56 and 90 days of curing respectively at the same displacement. The bearing ratio at a deformation of 5 mm for the reference mix cured for 0 days was 7.97 % which increased to 10.25 %,11.38 %, 14.04 % and 16.44 % at the end of 7, 28, 56 and 90 days of curing respectively. The increase in bearing ratio with the curing period is perhaps attributed to the pozzolanic reaction of marble dust with flyash-redmud mix resulting increase in the bearing ratio. It was reported by (Kumar *et al.* 2015) that a minimum bearing ratio of more than 80 % is required for base materials, 30–80 % for sub bases, and 10–30 % for sub-grade. The cured reference mix satisfies the requirement of the bearing ratio mentioned above as sub-grade material.

## *4.4 Undrained behaviour*

The undrained behaviour of the reference mix cured at different curing periods was studied. The deviator stress-axial strain curves for the reference mix cured for 7, 28, 56, and 90 days and at a confining pressure of 50 kPa, 100 kPa and 200 kPa respectively are shown in Figure 6(a), Figure 6(b), Figure 6(c) and Figure 6(d) respectively. Study of Figure 6(a), Figure 6(b), Figure 6(c) and Figure 6(d), reveals that, at a confining pressure of about 50 kPa, deviator stress at 20 % of the strain and at a curing period of 7 days, was 254.39 kPa which increased to 292.55 kPa, 349.79 kPa and 394.31 kPa respectively at the end of 28 days, 56 days and 90 days of curing. The increase in the deviator stress of the reference mix is due to induced cementation by the formation of pozzolanic products.




(a) (b)

Fig. 8. (a) Tensile stress-diametral strain curves for the reference mix at different curing period (b) Variation of tensile strength for the reference mix with curing period.

Similar behaviour was observed at other confining pressure and curing periods as evident from Figure 6(a), Figure 6(b), Figure 6(c) and Figure 6(d). Further study of Figures 6 (a) to (d), reveal that deviator stress increases with the increase in the confining pressure at all curing period. The increase in the deviator stress with increase in confining pressure is attributed to the increase in number of inter particles contacts resulting in higher deviator stress.

## *4.5 Durability*

Durability which can be defined as the ability of a material to retain stability and integrity over years of exposure to the destructive forces of weathering is one of the most important properties. Hence it was planned to conduct the durability study on the reference mix FA30RM70MD08. For these tests, specimens were prepared at the maximum dry density and optimum moisture content and then cured using a sponge method of curing as the specimen get dissolved in water during the wetting cycle. The specimen was wrapped in filter paper and placed inside a sponge and the sponge was kept in water for 5 hours followed by air drying of the specimen for 42 hours at room temperature, which completes single cycle of wetting and drying. The specimen was subjected to 12 such cycles of wetting and drying but brushing was omitted. Brushing of specimens has been known to cause uncertainty in the results because it is manual and hence could very well be affected by the consistency of technician's procedure. Replacing brushing by measuring the compressive strength of specimens after they are subjected to the 12 cycles of wetting-drying could provide a more consistent and convenient measures of the deterioration of the mix. It was suggested by (Shihata and Baghdadi 2001) that using the compressive strength of durability specimens without brushing as an indicator of resistance potential since it gives more consistent results.

Thus the specimens prepared without brushing were tested for unconfined compressive strength. Typical axial stress-strain curves obtained are presented in Figure. 7(a) and the variation of the unconfined compressive strength with curing are shown in Figure 7(b). Study of the Figure 7(a) and 7(b) reveals that the unconfined compressive strength of the mix increases significantly with the curing period. For example, the unconfined compressive strength of the reference mix at 7 days of curing 200.82 kPa which increased to 229.51 kPa, 335.54 kPa and 504.61 kPa for 28, 56 and 90 days of curing respectively.

The comparison of unconfined compressive strength before and after the specimen was subjected to 12 cycles of wetting and drying is shown in Figure 7(c). Study of Figure 7(c) reveals that at 7 days of curing the unconfined compressive strength of the specimen prior to durability cycles was 87.24 kPa which increased 200.82 kPa after the durability cycles at the same curing period. Similar behaviour was observed at other curing periods as evident from Figure 7(c). This increase in unconfined compressive strength after the durability cycles is attributed to formation of pozzolanic products due to induced cementation.

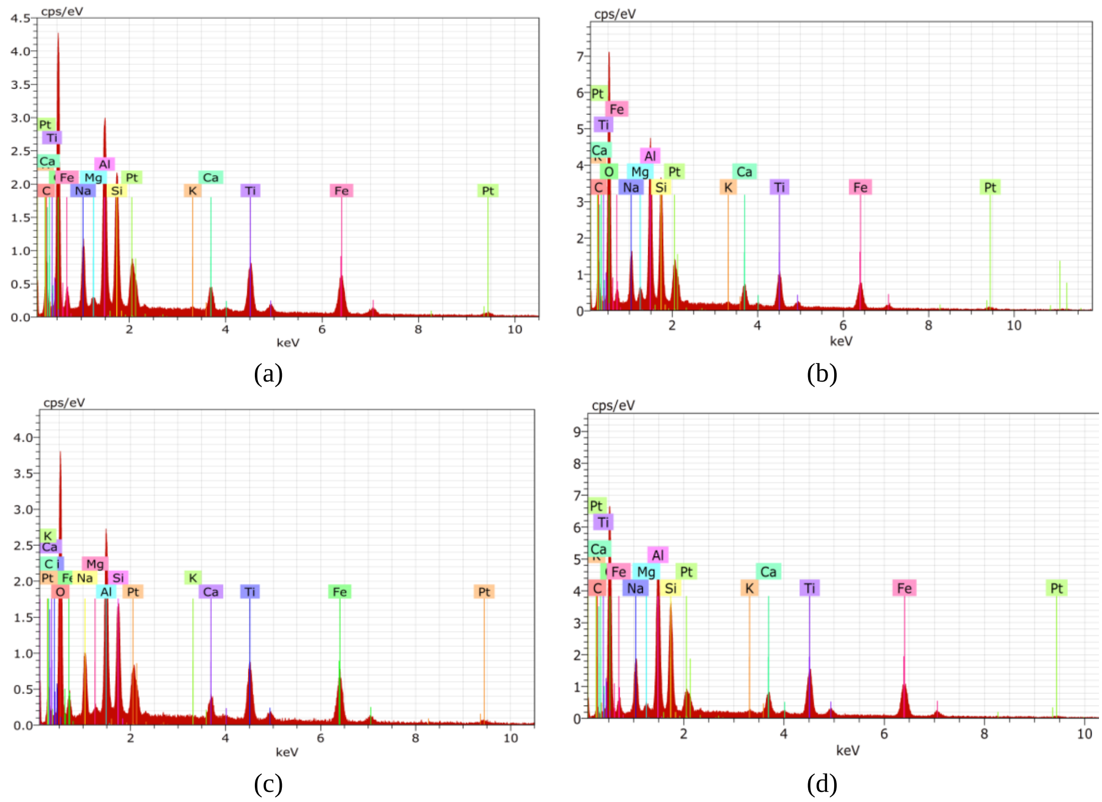



Fig. 9. Energy dispersive X-ray spectroscopy results on reference mix after (a) 7 days (b) 28days (c) 56 days (d) 90 days of curing.

## *4.6 Split tensile strength*

The split tensile tests were conducted on the reference mix FA30RM70MD08. Typical tensile stress-diametral strain curves obtained are presented in Figure 8(a) and the variation of the split tensile strength with curing period is shown in Figure 8(b). Study of Figure 8(a) and 8(b) reveals that there is an increase in the split tensile strength with curing period. For example, the split tensile strength of the reference mix at 7 days of curing was 52.04 kPa which increased to 70.41 kPa, 93.37 kPa and 131.63 kPa when the curing period is raised to 28, 56 and 90 days respectively. This increase in the split tensile strength with the increase in curing period is attributed to the formation of pozzolanic products due to induced cementation.

## 4.7 *Energy dispersive X-Ray spectroscopy*

The energy dispersive X-ray spectroscopy analysis of the reference mix FA30RM70MD08 cured for 7, 28, 56 and 90 days curing are shown in Figure. 9 (a) to 9(d) and the elemental composition with respect to percentage weight is shown in Table 2 and the summary of the analysis of the results is shown in Table 3.

Table 2
Elemental composition of the reference mix with respect to percentage weight after 7, 28, 56 and 90 days of curing

| EL | AN | Series | 7 days | 28 days | 56 days | 90 days |
|---|---|---|---|---|---|---|
| O | 8 | K-Series | 38.56 | 40.50 | 37.37 | 38.99 |
| Fe | 26 | K-Series | 16.39 | 13.38 | 20.00 | 19.49 |
| C | 6 | K-Series | 11.60 | 12.08 | 7.52 | 3.17 |
| Ti | 22 | K-Series | 8.29 | 7.06 | 9.77 | 10.75 |
| Al | 13 | K-Series | 7.84 | 8.02 | 7.95 | 9.57 |
| Si | 14 | K-Series | 5.72 | 6.31 | 5.04 | 6.68 |
| Pt | 78 | M-Series | 5.42 | 6.09 | 6.12 | 3.56 |
| Na | 11 | K-Series | 3.87 | 3.62 | 4.17 | 4.71 |
| Ca | 20 | K-Series | 2.18 | 2.39 | 1.98 | 2.20 |
| Mg | 12 | K-Series | 0.12 | 0.55 | 0.07 | 0.19 |
| K | 19 | K-Series | 0.00 | 0.01 | 0.03 | 0.04 |

Table 3
Summary of energy dispersive X-ray spectroscopy analysis for the mix FA30RM70MD08

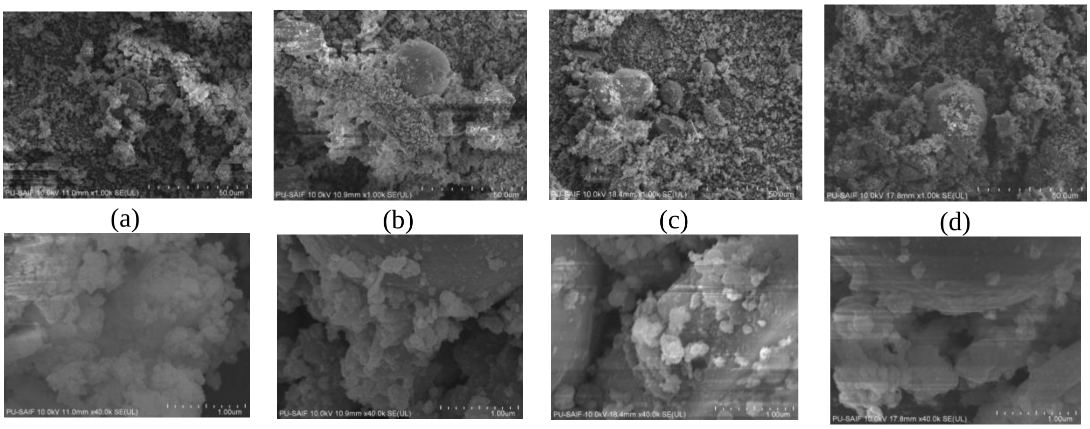
| Curing Period | Ca:Si ratio | Si:Al ratio |
|---|---|---|
| 7 days | 0.3811 | 0.7296 |
| 28 days | 0.3788 | 0.7868 |
| 56 days | 0.3929 | 0.6340 |
| 90 days | 0.4251 | 0.6980 |

The emissions of Ca, Si and O confirm the formation of pozzolanic compound like *C-S-H* leading to increase in the unconfined compressive strength, bearing ratio, deviator stress and split tensile strengthof the reference mix as evident from Table 2.Study of Table 3 reveals an increase in Ca:Si ratio and decrease in Si:Al ratio when the curing period is raised from 7 days to 90 days. The Ca:Si ratio at 7 days was .3811 which increased to .3788, .3929 and .4251 at 28, 56 and 90 days of curing respectively indicating improvement in unconfined compressive strength, bearing ratio, deviator stress and split tensile strength with the increase in curing period. Further study of Table 3reveals that the Si/Al ratio at 7 days of curing was 0.7296 which decreased to 0.6980 at 90 days curing indicating improvement in unconfined compressive strength, bearing ratio, deviator stress and split tensile strength with the increase in curing period.

## 4.8 *Field emission scanned electron microscopy*

The field emission scanned electron microscopytests were conducted for the reference mix FA30RM70MD08 cured at 7, 28, 56 and 90 days are shown in Figure. 10.

The study of Figures 10(a) to (d) reveals that there is very less bonding among flyash and redmud particles after 7 days of curing. It is observed that the bonding among the particles improved and started forming cluster by deposition of cementing compounds on the surface of fly ash particles with increase in curing period to 28, 56 and 90 days. Figures 10(e) to 10(h) which are at greater magnification reveal the same also. The improvement in unconfined compressive strength, bearing ratio, deviator stress and split tensile strength is due to the formation of cementing compounds with the increase in the curing period and is confirmed by these Figures.



(a) (b) (c) (d)

(e) (f) (g) (h)

Fig. 10. Field emission scanned electron micrograph of the reference mix at (a) 7 days (10 kV 11mm×1.00k 50 um) (b) 28 days (10 kV 10.9mm×1.00k 50 um) (c) 56 days (10 kV 18.4mm× 1.00k 50 um) (d) 90 days (10 kV 17.8mm×1.00k 50 um) (e) 7 days (10 kV 11mm×40.00k 1.0 um) (f) 28 days (10 kV 10.9mm×40.00k 1.0 um) (g) 56 days (10 kV 18.4mm×40.00k 1.0 um) (h) 90 days (10 kV 17.8mm×40.00k 1.0 um)

## 5. Conclusion

Geotechnical characterization of flyash-redmud mix stabilized with marble dust has been carried out. The dry unit weight of the mix FA30RM70 is maximum at a marble dust content of 8%.Beyond a marble dust content of 8 %, the dry unit weight decreased. The optimum moisture content increased with addition of marble dust to the mix FA30RM70. Theunconfined compressive strength, split tensile strength, bearing ratio and deviator stressof the mix FA30RM70MD08 increases with the increase in curing period. The durability of the mix FA30RM70MD08 improved after the wetting and drying cycles and this trend is same at all the curing periods. The energy dispersive X-ray spectroscopy andfield emission scanned electron microscopy studies have shown the formation of cementation compounds with the addition of marble dust to the mix FA30RM70.

Thus by this study an attempt has been made to provide an insight into the geotechnical characterisation of flyash-redmud mix stabilised with marble dust. The improved behaviour of the reference mix (FA30RM70MD08) will boost the construction of sub grade in rural roads especially in areas where these wastes are available in abundance. Also, its use will also provide a means of consuming large quantities of flyash, redmud and marble dust.

### References

Behera, B. and Mishra, M.K. (2012). California bearing ratio and Brazilian tensile strength of mine overburden-fly ash-lime mixtures for mine haul road construction. Geotechnical and Geological Engineering, 30(2), 449-459.

Bhattacharjee, S. and Bandyopadhyay, K. (2011). Flexural strength of fly ash sub grade stabilized with lime and cement. Proceedings of Indian Geotechnical Conference, Dec 15-17, Kochi, India.

Chatterjee, A. K. (2001). Manufacture of PPC in India: Effective use of fly ash as a blending material. Proc. National Seminar on Utilization of Fly Ash in Water Resources Sector, Central Soil and Materials Research Station, New Delhi, India, 29–41.

Consoli, N. C., Montardo, J. P., Prietto, P.D.M. and Pasa, G.S. (2001). Engineering behaviour of sand reinforced with plastic waste. Geotechnical and Geo environmental Engineering, 128(6), 462-472.

Das, S. K. and Yudbhir, (2005). Geotechnical characterization of some Indian flies ashes. Journal of Materials in Civil Engineering, 17 (5), 544–552.

Dempsey, B.J. and Thompson, M.R. (1973). Effect of Freeze – Thaw parameters on the durability of stabilized materials. Transportation Engineering, Series no 4, Illinois cooperative highway research program series no 136, report project IHR-401, university of Illinois, Urbana, Illinois.

Fraay, A., Bijen, J.M. and Vogelaar, P. (1990). Cement-stabilized fly ash base courses.Cement Concrete Research, 12(4), 279–291.

Gamble, J.C. (1971). Durability, plasticity, classifications of shales and other argillaceous rocks. Ph. D Thesis, University of Illinois, USA.

Garg, M., Singh, M. and Kumar R. (1996). Some aspects of the durability of a phosphogypsum-lime-fly ash binder. Construction and Building Materials, 10(4), 273-279.

Ghosh, A. and Subbarao, C. (2006). Tensile strength bearing ratio and slake durability of class F fly ash stabilized with lime and gypsum. Journal of Materials in Civil Engineering, 18(1), 18-27.

Ghosh, A. and Subbarao, C. (1998). Hydraulic conductivity and leachate characteristics of stabilized fly ash. Journal of Environmental Engineering, 124(9), 812-820.

Ghosh, A. and Subbarao, C. (2001). Microstructural development in fly ash modified with lime and gypsum.Journal of Materials in Civil Engineering, 13(1), 65-70.

Ghosh, A. (2010). Compaction characteristics and bearing ratio of pond ash stabilized with lime and phosphogypsum. Journal of Materials in Civil Engineering, 22(4), 343-351.

Ghosh, A. and Subbarao, C. (2007). Strength characteristics of class F fly ash modified with lime and gypsum. Journal of Geotechnical and Geoenvironmental Engineering, 133(7), 757 – 766.

He, J. and Zhang, G. (2011). Geopolymerization of red mud and fly ash for civil infrastructure applications. Geo-Frontiers, 1287-1296, doi: 10.1061/41165(397)132.

Jadhao, P.D. and Nagarnaik, P.B. (2008). Influence of polypropylene fibres on engineering behaviour of soil-fly ash mixture for road construction. Electronic Journal of Geotechnical Engineering, 13(C), http://www.ejge.com/2008/Ppr0840/Abs0840.htm.

Joshi, R. C. and Lothia, R. P. (1997). Fly ash in concrete: production, properties and uses. CRC Press, 13-Nov-1997 - Technology & Engineering - 128 pages.

Kaniraj, S.R. and Havanagi, V.G. (1999). Geotechnical characteristics of fly ash-soil mixtures.International Journal of Geotechnical Engineering, 30(2), 129-146.

Kaniraj, S. R. and Gayathri, V. (2003). Geotechnical behaviour of fly ash mixed with randomly oriented fiber inclusions. Geotextiles and Geomembranes, 21(3), 123-149.

Kaniraj, S. R. and Gayathri, V. (2004). Permeability and consolidation characteristics of compacted fly ash. Journal of Energy Engineering, 130(1), 18-43.

Kim, S.S. and Chun, B.S. (1994). The study on a practical use of wasted coal fly ash for coastal reclamation. XIII Proceedings of international Conference on Soil Mechanics and Foundation Engineering, International Society for Soil Mechanics and Foundation Engineering, 1607–1612.

Kolias, S., Rigopoulou, V. K. and Karahalios A. (2005). Stabilization of clayey soils with high calcium fly ash and cement. Cement and Concrete Composites, 27(2), 301-313.

Kumar, A., Singh, G. and Bala, N. (2013). Evaluation of flexural strength of epoxy polymer concrete with red mud and fly ash. International Journal of Current Engineering and Technology, 3(5), 1799-1803.

Kumar, D., Gupta, A. and Kumar, N. (2014). Some geotechnical properties of coal fly ash and sand mixtures with different ratio using in highway & embankments. Global Journal of Researches in Engineering: (E) Civil and Structural Engineering, 14(5), https://globaljournals.org/GJRE_Volume 14/5-Some-Geotechnical-Properties.pdf.

Kumar, S., Dutta,R.K., Mohanty,B. (2015). Potential of bentonite-lime-mix modified with phosphogypsum and reinforced with sisal fibres.Periodica Polytechnica Civil Engineering, *59(2), 143–154*.

Lo, S.R. and Wardani, S.P.R. (2002). Strength and dilatency of a silt stabilized by a cement and fly ash mixture.Canadian Geotechnical Journal, 39(1), 77-89.

Mishra, M. K. and Karanam, U.M. R. (2006). Geotechnical characterization of fly ash composites for backfilling mine voids. Geotechnical and Geological Engineering, 24(6), 1749 -1765.

Mishra, N.K. (2012). Strength characteristics of clayey sub-grade soil stabilized with fly ash and lime for road works. Indian Geotechnical Journal, 42(3), 206-211.

Mishra, R. S. and Mishra, B. (2015). Improvement in characteristics of expansive soil by using quarry waste and its comparison with other materials like cement and lime being used for soil improvement - A comparative study. International Journal of Innovative Research in Science, Engineering and Technology, 4(8), 7416-7431.

Okagbue, C.O. and Onyeobi, T. U. S. (1999). Potential of marble dust to stabilise red tropical soils for road construction. Engineering Geology, 53(3-4), 371-380.

Pandian, N.S. (2004). Fly ash characterization with reference to geotechnical applications. Journal of the Indian Institute of Science, 84(6), 189–216.

Paya, J., Monzo, J., Borrachero, M.V., Peris-Mora, E. andAmahjour, F. (1999). Mechanical treatment of fly ashes Part IV. Strength development of ground fly ash-cement mortars cured at different temperatures. Cement and Concrete Research, 30(4), 543-551.

Poran, C. J. and Ahtchi-Ali, F. (1989). Properties of solid waste incinerator fly ash. Journal of Geotechnical Engineering, 115(8), 1118–1133.

Reddy, B. V. V. and Gupta,A. (2005). Characteristics of soil-cement blocks using highly sandy soils. Materials and Structures, 38(6), 651-658.

Ribeiro, D.V., Labrincha, J.A. and Morelli, M.R. (2011). Potential use of natural red mud as pozzolan for Portland cement. Materials Research, 14(1), http://dx.doi.org/10.1590/S1516-14392011005000001.

Satyanarayana, P.V.V., Naidu, G., Adiseshu, P. S. and Reddy, P.P. (2012). A study on strength characteristics of fly ash, lime and sodium silicate mixtures at their free pouring conditions. International Journal of Computational Engineering Research, 2(4), 1102-1108.

Sharma, A., Habib, G. and Matsagar, V. M. (2013). Reuse of marble dust as fine aggregate in ultra-high performance concrete. ISWA World Congress, 7-11 October, Vienna.

Shi, C. (1996). Early microstructure development of activated lime- fly ash paste. Cement and Concrete Research, 26(9),1351-1359.

Shihata, S.A., Baghdadi, S.A. (2001). Simplified method to access freeze-thaw durability of soil cement. Journal of Material in Civil Engineering, 13(4), 243-247.

Singh, M. and Garg, M. (2007). Durability of cementing binders based on fly ash and other wastes. Construction and Building Materials, 21(11), 2012-2016.

Sivapullaiah, P. V. and Moghal, A. A. B. (2011). Role of gypsum in the strength development of fly ashes with lime. Journal of Materials in Civil Engineering, 23(2), 197-206.

Sutherland, H. B., Finlay, T. W. and Cram, I. A. (1968). Engineering and related properties of pulverised fuel ash. Journal of Institution of Highway Engineers, London, 15(6), 19–35.

Walker, P.J. (1995). Strength, durability and shrinkage characteristics of cement stabilized soil blocks. Cement and Concrete Composites, 17(4), 301-310.

Yousif, A.M., Rodgers, M. and Clifford, E. (2012). Absorption properties of modified red mud towards phosphate removal from its solutions. International Journal of Environmental Science and Development, 3(4), 354-356.

Zaharki, D. and Komnitsas, K. (2009). Effect of additives on the compressive strength of slag-based inorganic polymers. Global Nest Journal, 11(2), 137-146.

Zhang, J.R. and Xing, C. (2002). Stabilization of expansive soil by lime and fly ash. Journal of Wuhan University of Technology Materials Science, 17(4), 73-77.