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Geotechnical Characterization of Flyash-Redmud Mix Stabilized with Lime Sludge

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ABSTRACT

This paper presents the geotechnical characterization of flyash-redmud mix stabilized with lime sludge. Compaction tests were carried out on flyash-redmud and flyash-redmud-lime sludge mixes. The results of this study revealed that maximum dry unit weight increased with the increase in percentage of redmud in flyash. The optimum moisture content decreased with the increase in the content of redmud upto 20% in flyash. Beyond a content of 20% of redmud in flyash, the optimum moisture content increased. A mix containing 30% flyash and 70% redmud was identified and used for studying the compaction behaviour by varying the content of lime sludge. The maximum dry unit weight of the mix increased up to a lime sludge content of 2%. Beyond a lime sludge content of 2%, the dry unit weight decreased. A reference mix containing 30% flyash and 70% redmud, with 2% lime sludge was identified and used for studying the unconfined compressive strength, split tensile strength, bearing ratio, unconsolidated undrained triaxial behaviour and durability of the cured specimens. The curing period was varied from 7 days to 90 days. The results revealed 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 the same at all curing periods. The improved behaviour of the flyash-redmud-lime sludge mix will boost the construction of subgrade in roads. Further, its use will also provide environmental motivation for providing a means of consuming large quantities of flyash, redmud and lime sludge.

KEYWORDS: Flyash, Redmud, Lime sludge, Compaction, Unconfined compressive strength, Bearing ratio, Deviator stress, Durability, Split tensile strength, EDAX, FESEM.

INTRODUCTION

India has a total installed capacity of 100,000 MW of electricity generation. 73% of this capacity is based on thermal power generation. Indian flyashes have high ash content varying from 30% to 50%. On the other hand, an enormous quantity (2 million tons) of redmud is being generated in India, posing a serious threat to the environment. 4.5 million tons of lime sludge is being produced from paper industry, water softening plants and during the manufacturing of acetylene, sugar, fertilizers, sodium chromate and soda ash in India. The best way to handle these waste materials is to mix them

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together and use them for some engineering applications. This paper presents the geotechnical characterization of flyash-redmud-lime sludge mixes. A series of laboratory tests were carried out by varying the lime sludge content and curing period. The results obtained from these tests are presented and discussed in this paper for possible applications in civil engineering.

BACKGROUND

An inevitable consequence of development and industrial progress is generation of waste. As such, efficient waste management is a matter of international concern and several investigations have been carried out on utilization of waste materials. For flyash, studies were carried out for its geotechnical properties (Kaniraj and Havanagi, 1999; Pandian, 2004; Kumar et al., 2014), for its use in soil stabilization (Lo and Wardani, 2002; Singh and Garg, 2007), its use in roads and embankments (Ghosh and Subbarao, 2006; Jadhao and Nagarnaik, 2008), as well as in coastal land reclamation (Kim and Chun, 1994). Investigations were also carried out for the binding effects of several factors, such as lime and gypsum content and type, on strength development, pozzolanic reaction rate and chemistry of lime-pozzolan cement (Fraay et al., 1990; Ghosh and Subbarao, 1998; Gosh and Subbarto, 2001; Mishra and Karnam, 2006). Properties/characteristics of flyash individually or in combination with either lime, cement, gypsum or phosphogypsum in their different combinations 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 Cao, 2002; Kolias et al., 2005), durability (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; Ghosh, 1996), flexural strength (Walker, 1995; Reddy and Gupta, 2005; Bhattacharjee and Bandyopadhyay, 2011), shear strength (Sutherland et al., 1968; Poran and Ahtchi, 1989; Fraay et al., 1990; Consoli et al., 2001; Ghosh and Subbarao, 2007; Sivapullaiah and Moghal, 2011), unconfined compressive strength (Behera and Mishra, 2012; Paya et al., 1999), XRD (Ghosh and Subbarao, 2001; Shi, 1996; Chatterjee, 2001; Ghosh and Subbarao, 2001; Kaniraj and Gayathri, 2003; Kaniraj and Gayathri, 2004; Das and Yudbhir, 2005) and SEM (Mishra and Karnam, 2006; Shi, 1996; Chatterjee, 2001; Ghosh and Subbarao, 2001; Kaniraj Gayathri, 2003; Das and Yudbhir, 2005; Joshi and Lothia, 1997). Further, researchers have carried out various studies on comparison of physical properties between treated and untreated bauxite residue mud (Nikraz et al., 2007), its use as pozzolan for Portland cement (Ribeiro et al., 2011), lime-stabilized redmud mix for feasibility in road construction (Satayanarayana et al., 2012), absorption properties of modified redmud towards phosphate removal from its solutions (Yousif, 2012), utilization of redmud (Li and Wu, 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 CaO (Zaharki and Komnitsas, 2009), strength of redmud-based geopolymer concrete and mixture of redmud, micro-silica with flyash (Abhishek and Aswath, 2012), as well as flexural strength of epoxy polymer concrete with redmud and flyash (Kumar et al., 2013). Researchers also carried out studies on the effect of lime-stabilized sludge as landfill cover on refuse decomposition (Rhew and Barlaz, 1995), flyash and lime sludge as partial replacement of cement in mortar (Sahu and Gayathri, 2014) and lime sludge for stabilization of village road sub-base (Talukdar, 2015). From the literature presented above, it is concluded that no study has been carried out on flyash-redmud mix mixed with lime sludge. This paper presents the geotechnical characterization of flyash-redmud mix mixed with lime sludge for its possible applications in civil engineering.

MATERIALS USED AND EXPERIMENTAL PROCEDURE

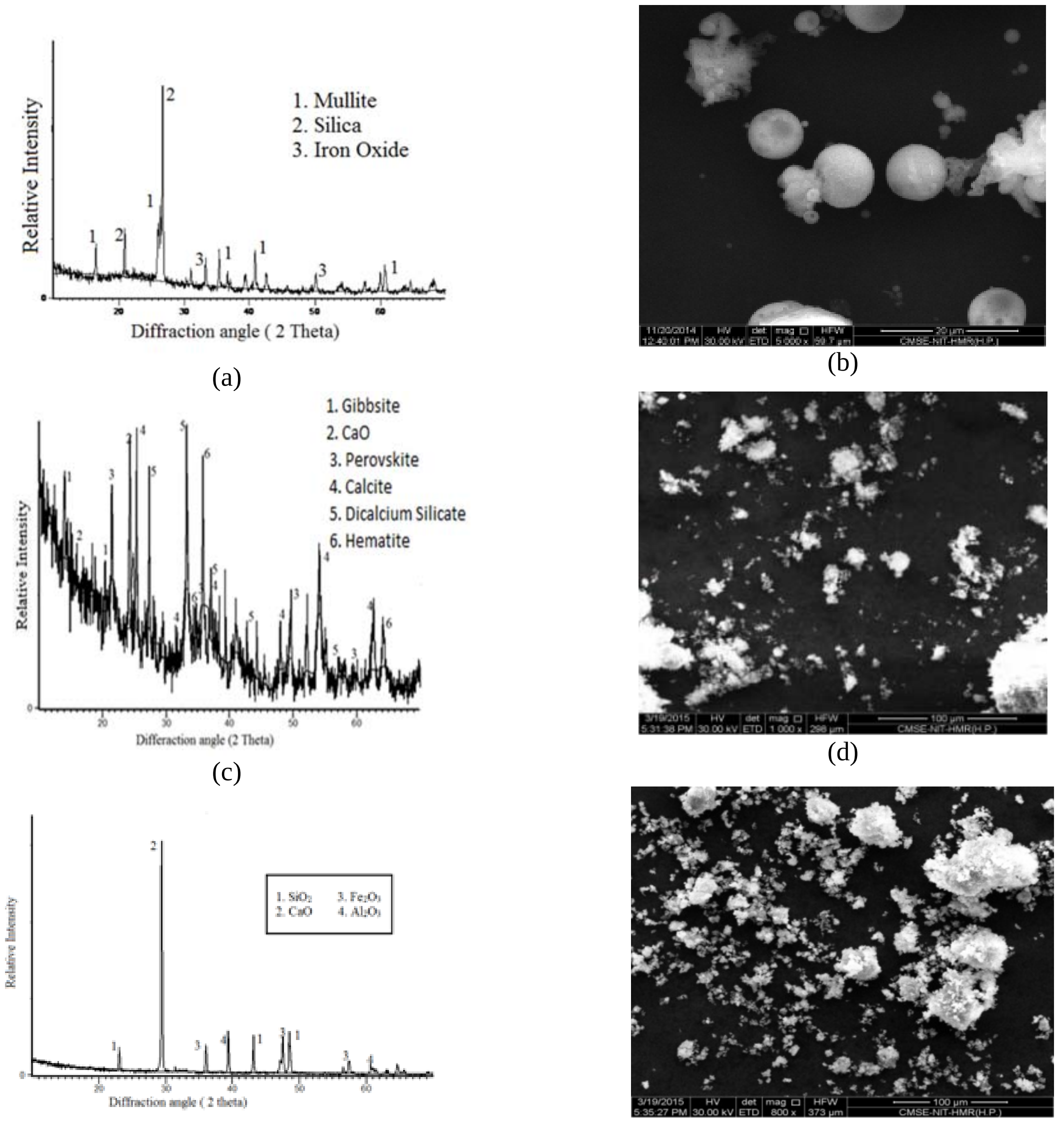
The flyash used in this study was procured from Ropar Thermal Power Plant, Punjab, India. Redmud used in the study was procured from Hindalko Industries, Limited at Renukoot, India and lime sludge was procured from Kuantum Papers, Ltd. The chemical properties of redmud, flyash and lime sludge are shown in Table 1.

Table 1. Chemical composition of redmud, flyash and lime sludge

	Redmud	Flyash	Lime Sludge
Fe_2O_3	33.1	3.7	0.8-2.5
Al_2O_3	18.2	37.80	0.8-5
SiO_2	8.8	45.60	2-8
CaO	2.7	5.35	35-70
TiO_2	19.6	-	-
Na_2O	5.8	-	0.8-2
SO_3	-	-	0.2-9
MgO	-	-	0.2-10
Loss on ignition	-	4.52	20-50

The flyash used in this investigation had a specific gravity of 1.90. The maximum dry unit weight and optimum water content as obtained by standard proctor test were found to be 12.65 kN/m^3 and 26%, respectively. The flyash is of class F type (as per ASTM C 618) and was chosen due to its availability in abundance as compared to class C flyash. The scanning electron micrograph (SEM) and X-ray diffractogram (XRD) of fly ash are shown in Figs.1 (a) and 1 (b), respectively. Study of Figs. 1(a) and 1 (b) shows the presence of mullite, silica, iron oxide and solid spheres with some irregular shape particles as well, respectively. The redmud used in the study had a specific gravity of 2.67, maximum dry unit weight of 14.52 kN/m^3 and optimum water content of 38%, respectively. The SEM and XRD of redmud are shown in Figs. 1 (c) and (d), respectively. Fig. 1(c) indicates prominent peaks of gibbsite and calcium oxide along with few peaks of hematite. Fig. 1(d) shows that the arrangement of the particles is relatively loose, small and poorly crystallized with high porosity.

The lime sludge used in this study had a specific gravity of 2.32. The SEM & XRD of lime sludge are shown in Figs.1 (e) and 1 (f), respectively. Fig. 1(e) shows the presence of lime, hematite, quartz and alumina, whereas Fig. 1(f) shows that the lime sludge particles are irregular in shape. Compaction, unconfined compressive strength, split tensile strength, bearing ratio, unconsolidated undrained triaxial and durability tests were conducted in accordance with IS 2720 (1980), IS 4332 (1970), IS 10082 (1981), IS 2720 (1987), IS 2720 (1993) and IS 4332 (1968), respectively. The failing specimens obtained from the unconfined compressive strength tests were used for the X-ray and SEM study. For easy reference and identification of specimens, a specific codification was used. For example, the codification FA60RM40LS02 will indicate a mix containing 60% flyash and 40% redmud, mixed with 2% lime sludge.



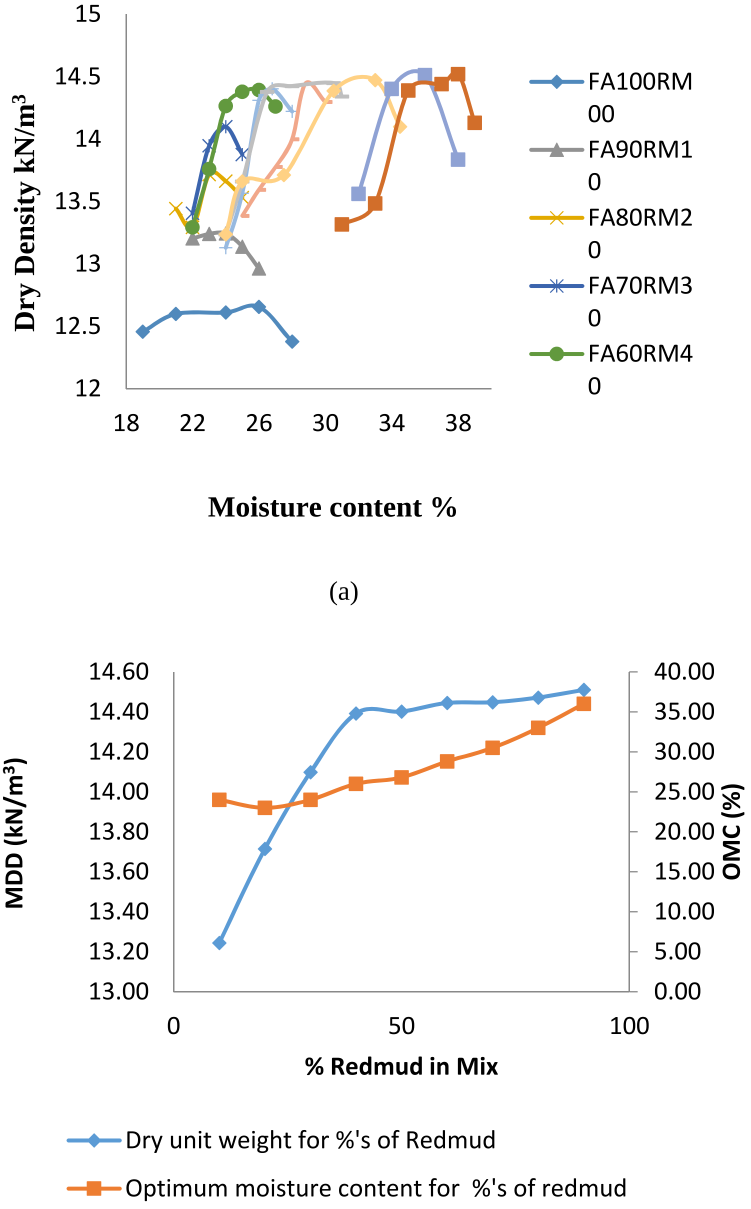
(a) (b) (c) (d) (e) (f)

Figure (1): (a) XRD of flyash, (b) SEM of flyash (30kV, X5000, 20µm), (c) XRD of redmud, (d) SEM of redmud (30kV, X1000, 100µm), (e) XRD of lime sludge and (f) SEM of lime sludge (30kV, X800, 100µm)

RESULTS

Compaction

Compaction tests on the mixes of flyash and redmud were carried out. The curves are shown in Fig. 2 (a), whereas the variation of the optimum moisture content and maximum dry unit weight with varying redmud percentage is shown in Fig. 2 (b).



(a)

(b)

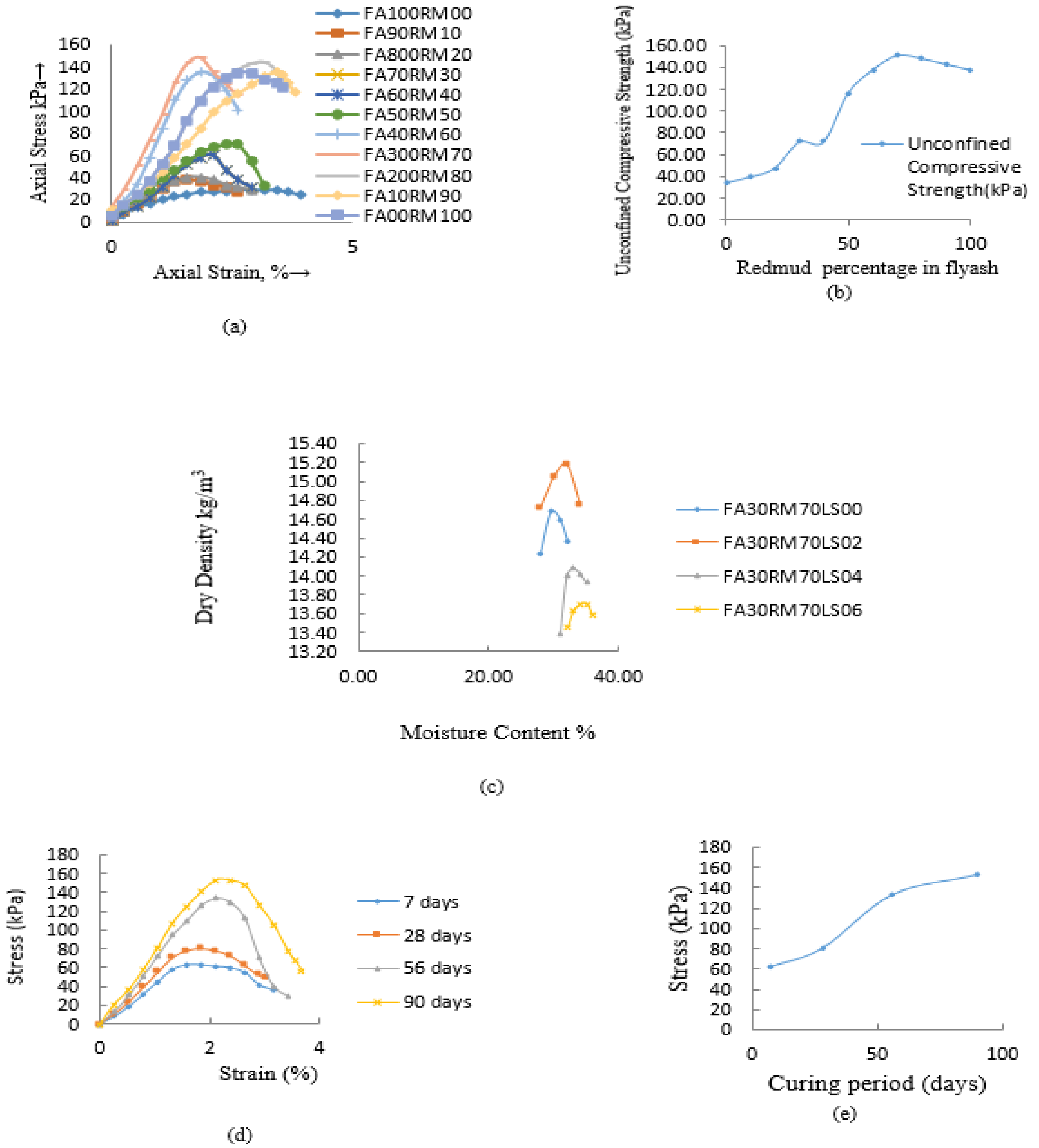
Figure (2): (a) Compaction curves for flyash-redmud mixes and (b) Variation of moisture content with varying percentage of redmud and variation of maximum dry unit weight with percentage of redmud

Study of Fig. 2 (b) reveals that the optimum moisture content decreased with the increase in the content of redmud upto 20% in flyash. The decrease in the optimum moisture content is attributed to the dominance of flyash particles having less 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 an increasing amount of fines (redmud having larger surface area) in the composite, requiring more water for lubrication due to increased surface area. Study of Fig. 2 (b) also reveals that the maximum dry unit weight increases with the increase in percentage of redmud in flyash. This increase in the dry unit weight is attributed to the higher specific gravity of redmud in comparison to flyash in the mix. In order to decide the optimum mix of flyash and redmud, it was decided to conduct unconfined compressive strength tests. The axial stress and strain curves are shown in Fig. 3(a) and the variation of unconfined compressive strength is shown in Fig. 3(b). Study of Fig. 3(a) 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 in an 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.

The compaction curves for the mix FA30RM70 with varying content of lime sludge are shown in Fig. 3 (c). Study of Fig. 3 (c) reveals that the maximum dry unit weight of the mix FA30RM70 increased up to a lime sludge content of 2 %. This increase in the dry unit weight is attributed to the improved gradation of the mix FA30RM70LS02, resulting in an increase in dry unit weight. Beyond a lime sludge content of 2 %, the dry unit weight decreased. The decrease in dry unit weight is attributed to the fact that lime present in the lime sludge reacts quickly with flyash-redmud mix, resulting in base exchange aggregation and flocculation, leading to an increase in void ratio of the mix. This results in the decrease in the dry unit weight of the flyash-redmud mix. Study of this figure reveals that the optimum moisture content increased with addition of lime sludge to the mix FA30RM70. This increase in optimum moisture content is attributed to the fact that additional water is held within the flocs as a result of flocculation due to lime present in the lime sludge reaction. Based upon the compaction studies reported above, reference mix FA30RM70LS02 was selected for further experimental work.

Unconfined Compressive Strength

The axial stress-strain curves for the reference mix FA30RM70LS02 cured for 7, 28, 56 and 90 days are shown in Fig. 3 (d) and the variation of the unconfined compressive strength with the curing period is shown in Fig. 3(e). The study of Figs. 3 (d) and 3(e) reveals that the unconfined compressive strength increased significantly with the increase in the curing period. For example, the unconfined compressive strength of the reference mix at 7 days of curing was 62.59 kPa and increased to 80.63 kPa, 133.59 kPa and 153.05 kPa for 28, 56 and 90 days of curing, respectively. The increase in unconfined compressive strength with the curing period is perhaps attributed to the pozzolanic reaction of lime sludge with flyash-redmud mix, resulting in an 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 curves for the reference mix FA30RM70LS02 at curing periods of 7, 28, 56 and 90 days are shown in Fig. 4.



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

Figure (3): (a) Axial stress *versus* strain for the flyash-redmud mixes, (b) Variation of unconfined compressive strength with percentage of redmud, (c) Compaction curves for the mix FA30RM70LS02, (d) Axial stress- strain curve for the mix FA30RM70LS02 with curing period and (e) Variation of unconfined compressive strength for the reference mix with curing period

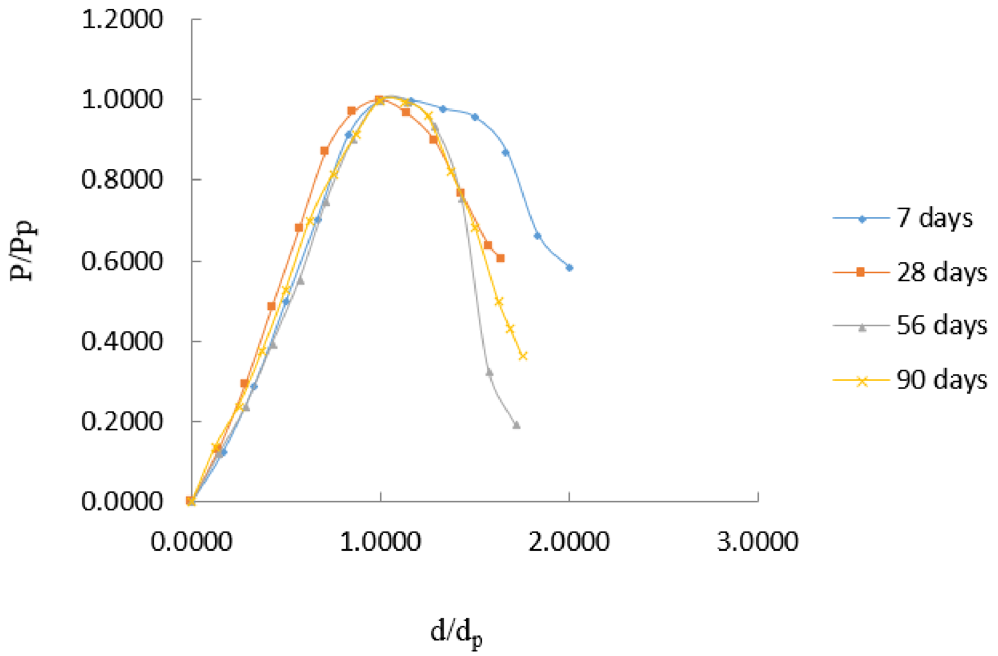


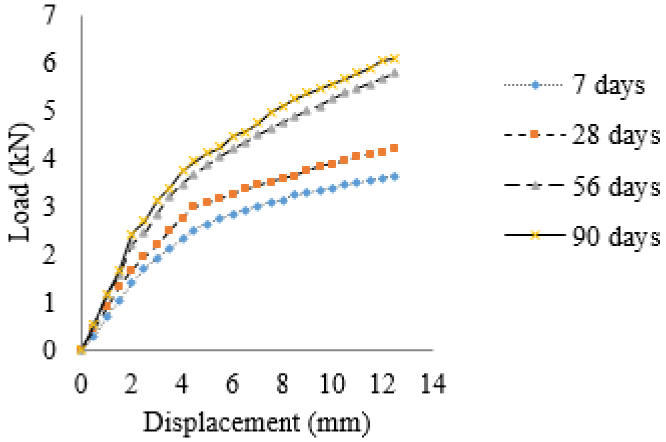
Figure (4): Normalized stress-strain curves for reference mix FA30RM70LS02 at different curing periods

Study of Fig. 4 reveals that the post-failure behaviour is ductile. The ductile behaviour decreases with the increase in the curing period. This may be attributed to the enhanced cementation due to formation of pozzolanic products decreasing the post-failure ductile behaviour.

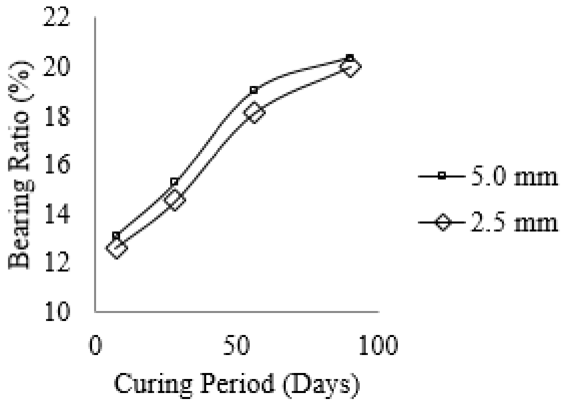
California Bearing Ratio

The load-displacement behaviour of reference mix FA30RM70LS02 cured for 7, 28, 56 and 90 days is shown in Fig. 5 (a). The variation of bearing ratio at a displacement of 2.5 mm and 5mm, respectively, is shown in Fig. 5 (b).

Study of Figs. 5 (a) and 5(b) reveals that the bearing ratio of the reference mix at 7 days of curing, corresponding to a displacement of 2.5 mm, was 12.62% and increased to 14.51%, 18.12% and 20.02% for 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 7 days was 13.09% and increased to 15.24 %, 19.01% and 20.37% at the end of 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 lime sludge with flyash-redmud mix, resulting in an increase in the bearing ratio. Kumar et al. (2015) specified a minimum bearing ratio of more than 80% for base materials, 30%-80% for sub-bases and 10%-30% for sub-grades. The cured reference mix satisfies the requirement of the bearing ratio mentioned above as sub-grade material.



(a)

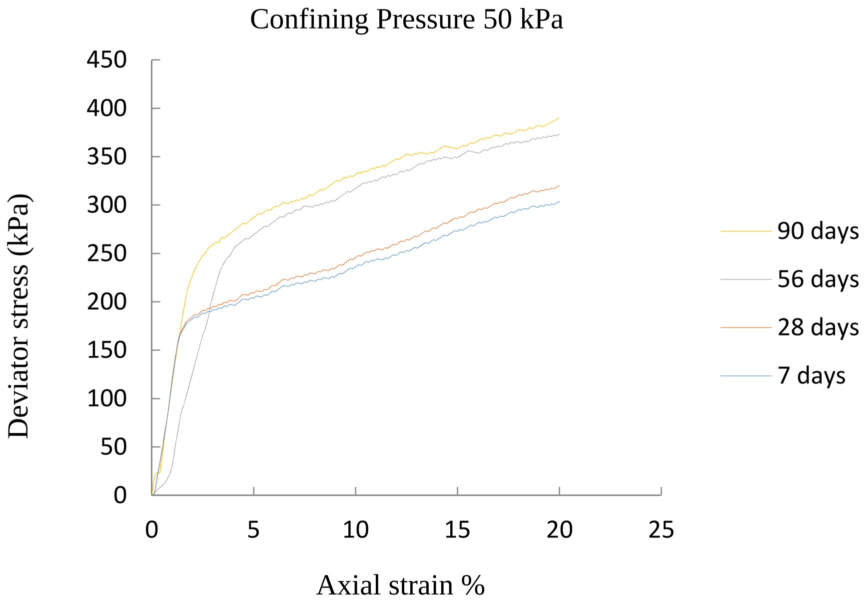


(b)

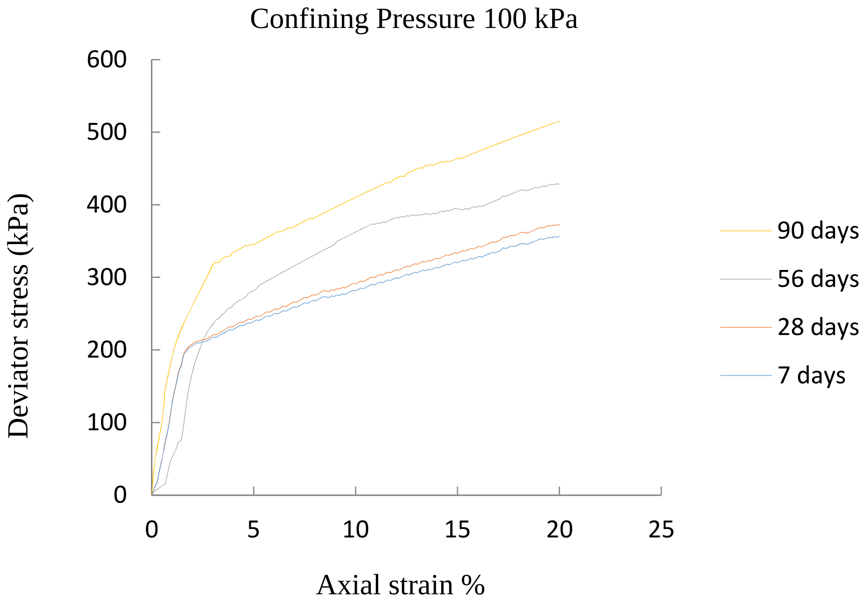
Figure (5): (a) Load-deformation curves for the reference mix at different curing periods and (b)Variation of bearing ratio for the reference mix with cuing period

Undrained Behaviour

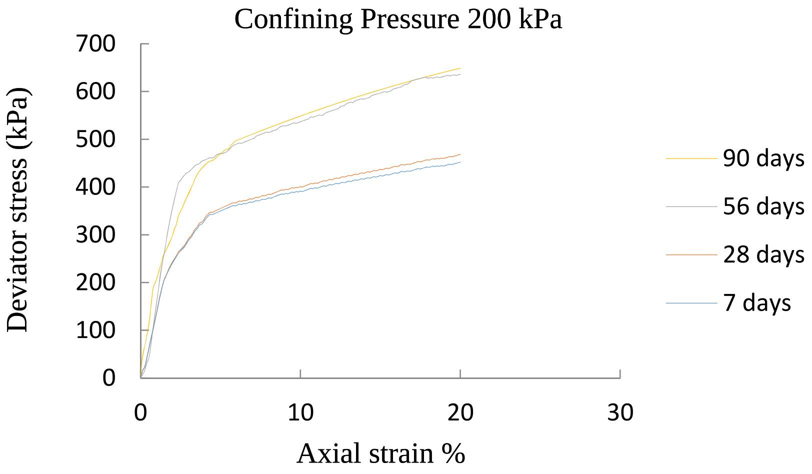
The undrained behaviour of the reference mix cured at different curing periods was studied. The deviator stress-axial strain curves for the reference mix cured for 7, 28, 56 and 90 days at a confining pressure of 50 kPa, 100 kPa and 200 kPa, respectively, are shown in Fig. 6(a), Fig. 6(b) and Fig. 6(c), respectively. Study of Fig. 6(a) reveals that at a confining pressure of 50 kPa, deviator stress at 20% of the strain and at a curing period of 7 days, was 320.11 kPa and increased to 373.11 kPa, 390.06 kPa and 451.54 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)



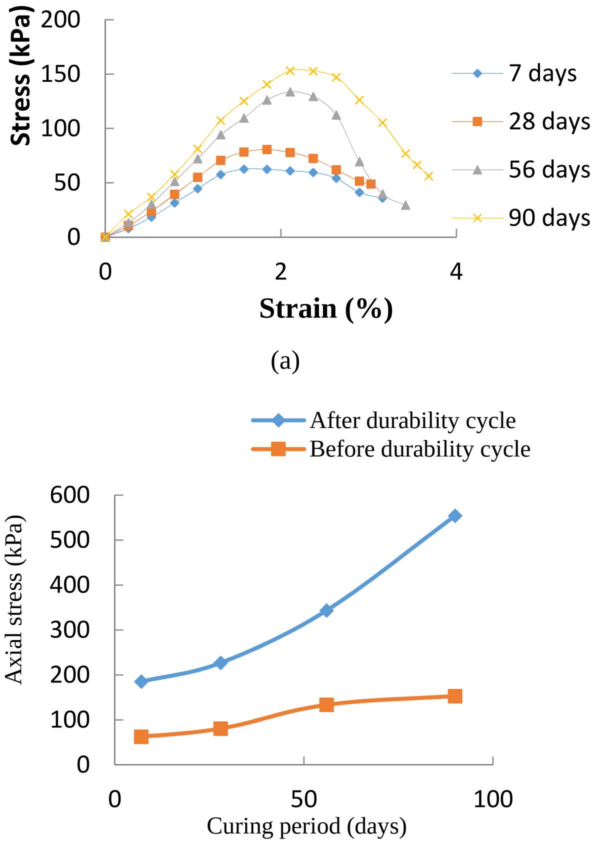
(c)

Figure (6): Variation of deviator stress-axial strain for the reference mix cured at different curing periods at a confining pressure of (a) 50 kPa, (b) 100 kPa and (c) 200 kPa

Similar behaviour was observed at other confining pressures and curing periods as evident from Figs. 6 (b) and 6(c). Further study of Figs. 6 (a) to 6(c) reveals that deviator stress increases with the increase in the confining pressure at all curing periods. The increase in deviator stress with the increase in confining pressure is attributed to the increase in the number of inter-particle contacts, resulting in a higher deviator stress.

Durability

Durability, which can be defined as the ability of a material to retain stability and integrity over years of exposure to destructive forces of weathering, is one of the most important properties. Hence, it was planned to conduct the durability study on the reference mix FA30RM70LS02. 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 gets 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 a 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 measure of deterioration of the mix. Shihata and Baghdadi (2001) also suggested 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 Fig. 7(a) and the variation of the unconfined compressive strength with curing period is shown in Fig. 7(b). Study of Fig. 7(a) and Fig. 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 was 185.17 kPa and increased to 226.9 kPa, 343.34 kPa and 554.03 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 Fig. 7 (b). Study of Fig. 7(b) reveals that at 7 days of curing, the unconfined compressive strength of the specimen prior to durability cycles was 62.59 kPa and increased to 185.17 kPa after the durability cycles at the same curing period. Similar behaviour was observed at other curing periods as evident from Fig. 7 (b). This increase in unconfined compressive strength after the durability cycles is attributed to the formation of pozzolanic products due to induced cementation.



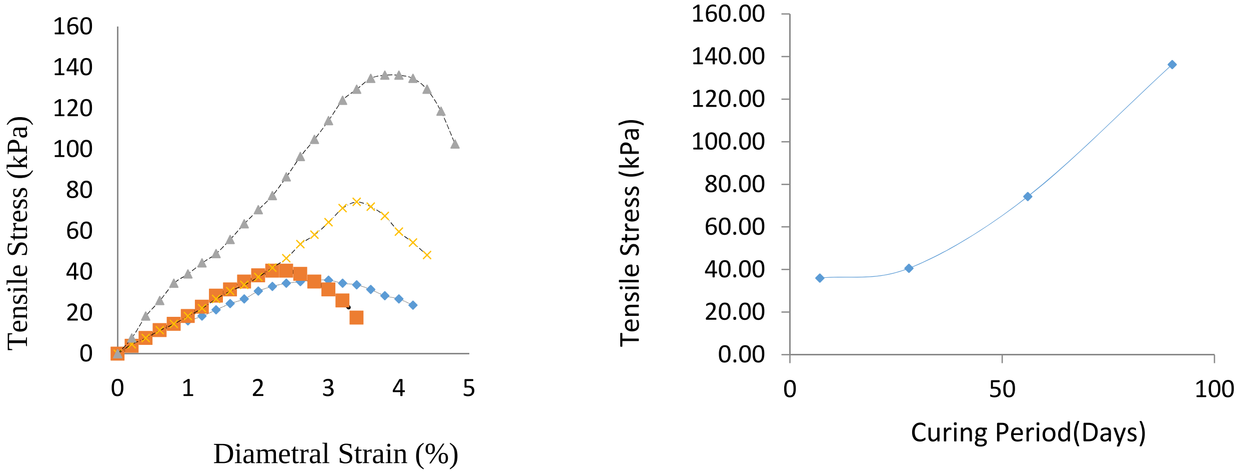
(a)

(b)

Figure (7) (a): Axial stress-strain curves for the reference mix at different curing periods after the durability cycle and (b) Comparison of the unconfined compressive strength before and after the durability cycle

Split Tensile Strength

Split tensile tests were conducted on the reference mix FA30RM70LS02. Typical tensile stress- diametral strain curves obtained are presented in Fig. 8(a) and the variation of the split tensile strength with curing period is shown in Fig. 8(b). Study of Fig. 8 (a) and Fig. 8(b) reveals that there is an increase in the split tensile strength with the curing period. For example, the split tensile strength of the reference mix at 7 days of curing was 35.97 kPa and increased to 40.56 kPa, 74.23 kPa and 136.22 kPa when the curing period is raised to 28, 56 and 90 days, respectively.



(a) (b)

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

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.

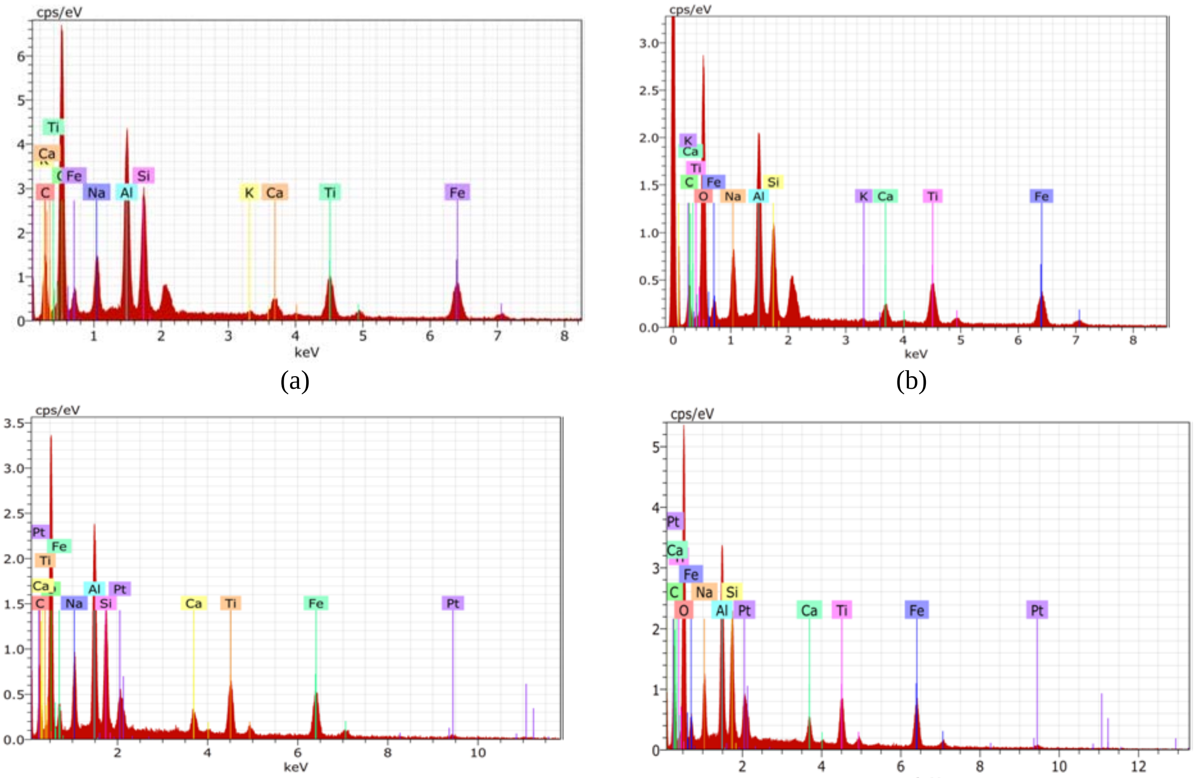
Energy Dispersive X-Ray Spectroscopy

The energy dispersive X-ray spectroscopy analysis of the reference mix FA30RM70LM02 cured for 7, 28, 56 and 90 days is shown in Figs. 9 (a) to 9 (d) and the elemental composition with respect to percentage weight is shown in Table 2.

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	7days	28 days	56 days	90 days
O	8	K-Series	42.42	42.05	38.41	38.79
Fe	26	K-Series	16.12	16.56	17.63	15.98
C	6	K-Series	14.10	10.50	13.78	16.94
Al	13	K-Series	8.28	9.94	7.82	6.86
Ti	22	K-Series	7.36	8.40	7.94	6.79
Na	11	K-Series	3.98	5.36	3.98	3.35
Si	14	K-Series	5.83	5.07	4.71	4.56
Ca	20	K-Series	1.82	1.96	1.88	1.97
K	19	K-Series	0.10	0.15		
Pt	78	M-Series			3.86	4.57

Summary of the energy dispersive X-ray spectroscopy analysis is given in Table 3.



(a) (b)

(c) (d)

Figure (9): XRD results on reference mix after (a) 7 days of curing, (b) 28 days of curing, (c) 56 days of curing and (d) 90 days of curing

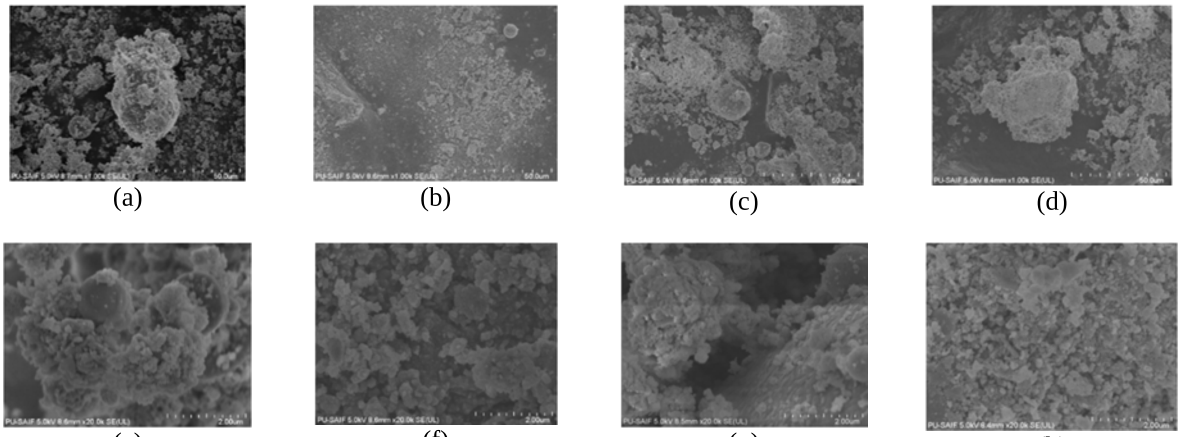
Table 3. Summary of energy dispersive X-ray spectroscopy analysis for the mix FA30RM70LS02

Curing Period	Ca:Si ratio	Si:Al ratio
7 days	0.3122	0.7041
28 days	0.3866	0.5101
56 days	0.3992	0.6023
90 days	0.4320	0.6647

The emissions of Ca, Si and O confirm the formation of pozzolanic compounds like *C-S-H*, leading to an increase in the unconfined compressive strength, bearing ratio, deviator stress and split tensile strength of the reference mix as evident from Table 2. Study of Table 3 reveals an increase in Ca:Si ratio and a decrease in Si:Al ratio when the curing period is raised from 7 days to 90 days. The Ca:Si ratio at 7 days of curing was 0.3122 and increased to 0.3866, 0.3992 and 0.4320 at 28, 56 and 90 days of curing, respectively, indicating an improvement in unconfined compressive strength, bearing ratio, deviator stress and split tensile strength with the increase in curing period. Further, study of Table 3 reveals that the Si:Al ratio at 7 days of curing was 0.7041 and decreased to 0.6647 at 90 days curing, indicating an improvement in unconfined compressive strength, bearing ratio, deviator stress and split tensile strength with the increase in curing period.

Field Emission Scanned Electron Microscopy

The field emission scanned electron microscopy results for the reference mix FA30RM70LS02 cured at 7, 28, 56 and 90 days are shown in Fig. 10.



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

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

Figure (10): Field emission scanned electron micrograph of the reference mix at (a) 7 days (5 kV 8.7mm×1.00k 50 µm) (b) 28 days (5 kV 8.6mm×1.00k 50 µm) (c) 56 days (5 kV 8.6mm×1.00k 50 µm) (d) 90 days (5 kV 8.6mm×1.00k 50 µm) (e) 7 days (5 kV 8.7mm×20.00k 2.0 µm) (f) 28 days (5 kV 8.7mm×20.00k 2.0 µm) (g) 56 days (5 kV 8.7mm×20.00k 2.0 µm) and (h) 90 days (5 kV 8.7mm×20.00k 2.0 µm)

Study of Figs. 10 (a) to 10 (d) reveals that there is much less bonding among flyash particles after 7 days of curing. With the increase in curing period to 28, 56 and 90 days, it was observed that the bonding among the particles improved, starting to form a cluster by deposition of cementing compounds on the surface of flyash particles. Figs. 10(e) to 10(h) also reveal the same at greater magnification. These figures confirm that 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.

CONCLUSIONS

An experimental study is carried out to geotechnically characterize flyash-redmud mix stabilized with lime sludge. Various tests, such as compaction, unconfined compressive strength, split tensile strength, bearing ratio, unconsolidated undrained triaxial and durability tests, were conducted on flyash-redmud mix stabilized with lime sludge. The study brings forth the following conclusions.

1. The maximum dry unit weight increases with the increase in percentage of redmud in the flyash. The optimum moisture content decreased with the increase in the content of redmud upto 20% in flyash. Beyond a content of 20% of redmud in flyash, the optimum moisture content increases. The maximum dry unit weight of the mix FA30RM70 increased up to a lime sludge content of 2%. Beyond a lime sludge content of 2 %, the dry unit weight decreased.
2. The axial stress of flyash increased with the addition of redmud up to a percentage of 70 %. Beyond a redmud content of 70% in flyash, the axial stress decreased.
3. The unconfined compressive strength, split tensile strength, bearing ratio and deviator stress of the reference mix increased with the increase in curing period.
4. The durability of the reference mix improved after the wetting and drying cycles. The trend is the same at all curing periods.
5. The FESEM-EDAX studies proved the formation of cementation compounds with the addition of lime sludge to the reference mix. These cementing

compounds were responsible for the improvement of the unconfined compressive strength, split tensile strength, bearing ratio and deviator stress with the increase in the curing period.

On the whole, this study has attempted to provide an insight into the geotechnical characterization of flyash-redmud mix stabilized with lime sludge. The improved behaviour of the flyash-redmud-lime sludge mix will boost sub-grade construction in roads. Further, its use will also provide an environmental motivation for providing a means of consuming large quantities of flyash, redmud and lime sludge.

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