Load Bearing Strength of Fly Ash Modified with Cement and Waste Sludge

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Abstract: *Roadways have a high potential for utilization of large volume of the fly ash stabilized mixes. In this study, an attempt has been made to investigate the use of Class F fly ash mixed with lime precipitated electroplating waste sludge–cement as a base material in highways. A series of tests were performed on specimens prepared with fly ash, cement and lime precipitated waste sludge. California bearing ratio (CBR) tests were conducted for 70%-55%fly ash, 8%cement, and 30%-45%waste sludge combinations. Results show that the load bearing strength of the mix is highly dependent on the waste sludge content, cement as well as curing period. The CBR value of fly ash mixed with electroplating waste sludge and cement has been increased to manifold and results the reduction in the construction cost of the pavement. The study also encourages the use of two potentially hazardous wastes for mass scale utilization without causing danger to the environment, vegetation, human and animal lives.*

Keywords: *Fly ash; cement, waste sludge, highway; CBR; load bearing strength*

1. Introduction

The demand of electricity power is increasing day by day. Major part of the electricity power is supplied by Thermal Power Plants where coal is used as fuel and a large quantity of fly ash emerges in the process. Fly ash creates different environmental problems like leaching, dusting and takes huge disposal area. Transforming this waste material into a suitable construction material may minimize the cost of its disposal and in alleviating environmental problems.

The electroplating or metal finishing industry has been playing a momentous role in the development and growth of numerous metal manufacturing and other engineering industries since the early part of this century. While electroplating operations have, in the course of time, become an essential and integral part of many engineering industries throughout the world, there has also been a steady growth of independent and small to medium scale electroplating industries, especially in the developing countries including, India. According to a report [1], in the year 2006 about 700,000 electroplating units were working in India, out of which about 5000 units were in Aligarh, Uttar Pradesh, India. The wastewater generated in Aligarh by lock industries, specially electroplating industries is around 250 million litres per day [2].

The fly ash studied in the present investigation belongs to Class F. Various studies on application of fly ash as bulk fill material are available [3, 4, 5] which demonstrated the possibility of utilizing huge amount of fly ash in construction of embankments, dykes and road subgrade. Lime stabilization is applied in road construction to improve subbase and subgrades, for railroads and airports construction, embankments, soil exchange in unstable slopes, backfill, canal linings, improvement of soil beneath foundation slabs, bridge abutments and retaining walls [6, 7, 8, 9]. It has been observed by investigators [10] that the improvement in the properties of fly ash due to lime takes place through inter-particle attraction causing flocculation and aggregation and the pozzolanic reaction, where calcium from the lime reacts with the soluble alumina and silica available in the fly ash in the presence of water to produce stable calcium silicate hydrates (C-S-H), calcium aluminate hydrates (C-A-H) and calcium aluminosilicate hydrates (C-A-S-H) which generate long-term strength gain. The CBR studies on incinerated sewage sludge ash (ISSA) mixed with cement and soil-fly ash reinforced

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with fibres, fly ash mixed with geomaterials, soft clay reinforced with geosynthetics and geogrid are available [11, 12, 13, 14, 15, 16]. However, the data on the California bearing ratio (CBR) of the mix containing fly ash-waste sludge-cement are not available in literature. Therefore, it becomes imperative to carry out CBR test to establish the pavement worthiness of these mixes. Keeping in view the danger caused due to heavy metals present in the electroplating waste sludge the author [17] has already been stabilized the electroplating waste sludge by using lime, fly ash and cement properly. Hence, this study paves the way for utilizing these wastes in various highway engineering applications.

2. Test Material

The materials used are:
(i) Fly ash
(ii) Electroplating Waste Sludge
(iii) Lime
(iv) Ordinary Portland Cement (OPC)

2.1. Fly Ash (FA)

Fly ash was procured from Harduaganj thermal power plant located at 16 km from Aligarh City, Uttar Pradesh (India). This power plant consist of 440 MW pulvarised coal units, producing 25 trucks of fly ash and bottom ash per day which is about 1500 tonnes fly ash and 500 tonnes of bottom ash [18]. For the present investigation, dry fly ash from hoppers was collected in polythene bags.

2.1.1. Physical Properties

The physical properties fly ash is shown in Table–1. The grain size distribution was determined using sieve analysis for particles larger than 75µ and hydrometer analysis for particles less than 75µ [19]. The grain size distribution curve for fly ash is shown in Fig. 1. It can be seen that the predominant size of particles in fly ash are silt sized (particle size between 0.600 mm to 0.0012 mm). The fly ash used in the present study can be classified as ML (silt of low compressibility) [20].

The specific gravity of fly ash was determined using pycnometer [21], which is equivalent to ASTM D 854–2000[22]. The specific gravity of fly ash is observed to be less than that of soils. The low specific gravity of fly ash may be due to high proportion of cenospheres or hollow particles [23].

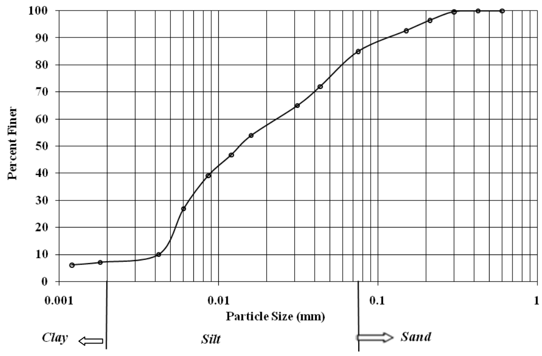


Fig. 1. Grain Size Distribution Curve of Harduaganj Fly ash

The principal chemical constituents of fly ash were silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3) and calcium oxide (CaO) as shown in Table–2. As per ASTM C 618-03[24], fly ash containing silica more than 35% and the combined percentage of silica, alumina and iron oxide more

Table 1. Physical Properties of Fly ash

S. No.	Constituent/Property	Value
1.	Colour	Grey
2.	Percent passing 75 µ sieve	88%
3.	Size of the particle	0.002-0.30mm
4.	Maximum dry density (MDD)	9.30 kN/m^3
5.	Optimum moisture content (OMC)	27.5%
6.	Specific gravity	2.02 at 27^{o}C
7.	Surface area	3060 cm^2/g
8.	Unburnt carbon	11.80%
9.	Classification	ML

Table 2. Chemical Properties of Fly ash

Constituent/Property	Value (%)
SiO_2	54.0
Al_2O_3	24.0
Fe_2O_3	12.0
CaO	02.0
MgO	01.0
SO_3	0.30
Loss on Ignition (Percent by Weight)	1.50

than 70% and CaO is less than 10%. Accordingly, Harduaganj fly ash is classified as Class F fly ash.

2.2. Electroplating Waste Sludge (S)

Electroplating waste sludge was collected in the form of filter cake from one of the electroplating industries in Aligarh City, India, in which Nickel, Chromium, Zinc and Cadmium plating is done, associated mostly of lock and other allied industries. There are more than 5000 number of big and small plants are working. These plants generate large quantity of waste. The quantity of articles plated, depends on shape, property desired for various articles. This industry is having 130 × 20 × 75 cm size tanks for collecting wastes of Nickel, Chromium, Zinc and Cadmium etc. There is no appropriate arrangement for proper disposal of these wastes, generally these wastes are disposed off directly in the drains without any treatment causing environmental and ground water pollution in the disposal area.

2.2.1. Physical Properties

The physical characteristics of electroplating waste sludge are shown in the Table–3.

2.2.2. Chemical Properties

The electroplating waste sludge was collected in the form of filter cake, comprises of 70% solid waste and 30% waste water (Fig. 2). The heavy metal concentration is shown in Table–4.

2.3. LIME (L)

The finely powdered white coloured lime was used as precipitator having the chemical composition shown in Table–5.

Table 4. Heavy Metal Concentration in Electroplating Waste Sludge

Metals	Concentration (mg/l or ppm)
Nickel	610
Chromium	630
Zinc	800
Cadmium	025
Copper	300
Lead	005

Fig. 2. Mixed Electroplating Waste Sludge before Treatment and Precipitation (Collected from Source)

2.4. CEMENT (C)

The cement used in this study was OPC-43 grade. The test on cement was conducted in accordance with IS: 269-1989[25]. The physical properties of cement are given in Table–6.

3. Preparation and Testing of Spesimens

The preparation and testing of specimens for California bearing ratio test were carried out in

Table 3. Physical Properties of Electroplating Waste Sludge

Constituent/Property	Value
Total Solids	128345mg/l
Total dissolved solids	6417.2mg/l
Total suspended solids	121927mg/l
Specific gravity	1.022
pH	1.2

Table 5. Chemical Composition of Lime

Constituent Properties	Value
Assay	95%
Chloride	0.01%
Sulphate	0.2%
Aluminium, iron and insoluble matters	1.0%
Arsenic	0.0004%
Lead	0.001%

Table 6. Physical Properties of OPC-43 grade Cement

Constituent/Property	Value
Specific surface cm^2/gm	3175
Soundness in mm	3.30
Compressive strength in MPa at 3 days	14.3
Compressive strength in MPa at 7 days	23.5
Setting time (minutes) Initial Final	 100 290

accordance with the IS Code [26] as described below:

The standard Proctor compaction test was carried out using the equipment and procedure as specified in the Indian Standard Code [27] to obtain maximum dry density (MDD) and optimum moisture content (OMC) of fly ash and fly ash-waste sludge mixes. The OMC of the fly ash was obtained as 27.5%.

The lime precipitated electroplating waste sludge [28] was dried, pulverized and sieved through 425µ IS sieve (Fig. 3). Fly ash was dried in oven for 24 hours and sieved through 425µ IS sieve. About 5 kg of fly ash, fly ash–waste sludge, fly ash-cement and fly ash-waste sludge-cement mix blends were taken and water equal to OMC was added.

The material was thoroughly mixed to achieve uniform mixing of water. The spacer disc was placed at the bottom of the mould and a filter paper over it; the first layer of wet mix blend is placed over it and compacted uniformly by 56 number of blows using light compaction hammer

Fig. 3. Dried and Pulverized Electroplating Waste Sludge after Treatment and Precipitation

weighing 2.6 kg having free fall of 310 mm. Similarly, the second and top layers (using collar) were placed by compacting each layer again by 56 number of blows.

After 24 hours the mould was kept under water for curing by placing filter paper on the top of the specimens along the surcharge weight of 5 kg over it. The specimens of different mixes were kept under water for different curing periods.

The free water collected in the mould has been removed and the specimens were allowed to drain off water in a vertical position for 15 minutes. The surcharge weight was again placed on the top of the specimens and the assembly with the base plate is placed in the compression testing machine. The plunger was brought in contact with the top surface of the specimen. A seating load of 4 kg was applied. The digital display meter for measuring load and penetration was the then set to zero. Now the load was applied at the rate of 1.25 mm/minute. The load values corresponding to penetrations 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10 and 12.5 mm were recorded.

The similar tests procedure were repeated for different combinations of mix such as 70%FA+30%S, 65%FA+35%S, 60%FA+40%S, 55%FA+45%S, 50%FA+50%S, 92%FA+08%C, 62%FA+08%C+30%S, 57%FA+08%C+35%S, 52%FA+08%C+40%S, 47%FA+08%C+45%S, 42%FA+08%C+50%S and 37%FA+8%C+55%S and the results of the average of three replicate tests for each combinations of mix and curing periods (fresh, 7, 28, and 90 days) were reported for further analysis.

4. Results and Discussion

The test results of fly ash, fly ash-cement, fly ash-waste sludge and fly ash-cement-waste sludge combinations, obtained from California bearing ratio tests are discussed below:

The results of California bearing ratio (CBR) tests on fresh and aged/cured specimens of

fly ash, fly ash-waste sludge, fly ash-8% cement and fly ash-waste sludge-8% cement and their combinations are discussed to bring out the load bearing characteristics of these mixes. The results are also discussed to bring out the effect of fresh, 7, 28 and 90 days of curing of the specimens, cement content and waste sludge on CBR values.

4.1. Load Bearing Characteristics of Fly ash

Figure 4 shows the results of CBR tests on fly ash. These results are also presented in Tables–7 and 8 to bring out the effect of fresh/aging on bearing strengths. The results suggest that:

The CBR value of fly ash under as compacted condition (fresh) has been obtained as 3.6% which is considered as poor CBR value. It has also been observed that the CBR value of fly ash improves on aging (Table-8). The improvement in CBR is of the order of 103% at 90 days of aging.

4.2. Load Bearing Characteristics of Fly ash-Cement Mix

Results of CBR tests on 92%FA+8% C have been presented in Fig. 5 and Tables–7 and 8 to bring out the effect of cement and curing on bearing strength. The results show that:

The 92%FA+8%C mix exhibits better CBR value than fly ash. The CBR value of this mix under fresh condition is 4.8% which is 34% more than fly ash under similar conditions. The increase in CBR value of this mix under fresh condition may be due to increase in the density of the mix on addition of fines (cement) in the fly ash. This observation is on similar lines as reported by the investigators [29].

The effect of curing is significant in this case (Table-8). The gain in the CBR value at 90 days

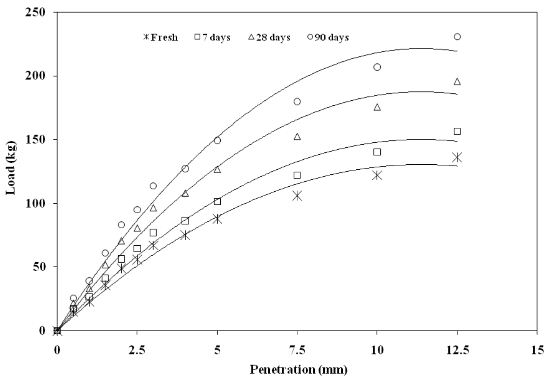


Fig. 4. Load Penetration Curves for Fly ash

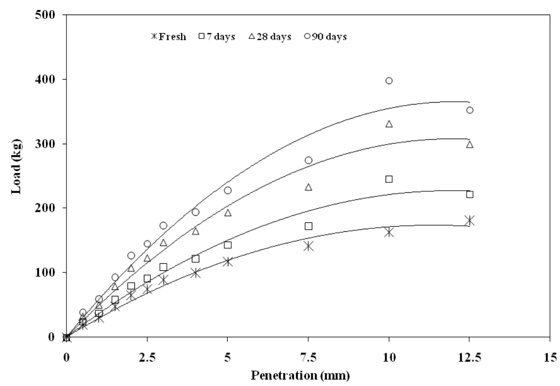


Fig. 5. Load Penetration Curves for 92%FA+8%C

Table 7. Results of CBR Test

Material	CBR Value (%)			
	Fresh	Aged (7 days)	Aged (28 days)	Aged (90 days)
Fly ash	3.60	4.30	6.00	7.30
70%FA+30%S	5.80	7.20	9.70	13.60
65%FA+35%S	6.50	9.70	14.59	19.22
60%FA+40%S	8.20	14.50	24.30	29.70
55%FA+45%S	9.40	17.00	26.80	31.70
50%FA+50%S	7.30	18.50	26.30	32.00
45%FA+55%S	9.20	19.50	28.70	34.20
92%FA+8%C	4.80	5.80	9.20	10.70
62%FA+8%C+30%S	7.20	9.70	13.60	17.00
57%FA+8%C+35%S	7.30	7.20	18.50	20.00
52%FA+8%C+40%S	9.70	14.60	30.00	34.00
47%FA+8%C+45%S	10.20	18.90	37.90	38.90
42%FA+8%C+50%S	9.70	19.40	38.90	43.70
37%FA+8%C+55%S	9.70	19.50	37.90	38.90

Table 8. Effect of Curing on CBR Values of Fly ash-Cement-Waste Sludge Mix Blend

Mix	CBR Values (%)				Percent Increase in CBR Values w.r.t. Fresh Specimen at			Percent Increase in CBR Values at		
								28 days	90 days	90 days
	Fresh	7 days	28 days	90 days	7 days	28 days	90 days	w.r.t. 7 days	w.r.t. 7 days	w.r.t. 28 days
Fly ash (FA)	3.60	4.30	6.00	7.30	19.00	67.00	103.00	40.00	70.00	22.00
70%FA+30%S	5.80	7.20	9.70	13.60	24.00	67.00	135.00	35.00	89.00	40.00
65%FA+35%S	6.50	9.70	14.59	19.22	49.00	125.00	195.00	50.00	98.00	32.00
60%FA+40%S	8.20	14.50	24.30	29.70	77.00	196.00	183.00	68.00	105.00	22.00
55%FA+45%S	9.40	17.00	26.80	31.70	81.00	185.00	237.00	58.00	86.00	18.00
50%FA+50%S	7.30	18.50	26.30	32.00	153.00	260.00	338.00	42.00	73.00	22.00
45%FA+55%S	9.20	19.50	28.70	34.20	112.00	212.00	269.00	47.00	75.00	19.00
92%FA+8%C	4.80	5.80	9.20	10.70	21.00	92.00	123.00	59.00	84.00	16.00
62%FA+30%S+8%C	7.20	9.70	13.60	17.00	35.00	89.00	136.00	40.00	75.00	25.00
57%FA+35%S+8%C	7.30	10.2	18.50	20.00	40.00	153.00	174.00	81.00	96.00	8.00
52%FA+40%S+8%C	9.70	14.6	30.00	34.00	51.00	209.00	250.00	105.00	133.00	13.00
47%FA+45%S+8%C	10.20	18.9	37.90	38.90	85.00	271.00	281.00	100.00	106.00	3.00
42%FA+50%S+8%C	9.70	19.4	38.90	43.70	100.00	301.00	350.00	100.00	125.00	12.00
37%FA+55%S+8%C	9.70	19.5	37.90	38.90	101.00	291.00	301.00	94.00	99.00	3.00

of curing has been observed as 47% when compared with fly ash under similar test condition. The similar trend have reported [30] for fly ash-cement mix.

4.3. Load Bearing Characteristics of Fly ash-Waste Sludge Mix

The results of CBR tests are presented in Figs. 6 to 11 and Tables–7 and 8 to bring out the effects of waste sludge and curing on CBR values of the fly ash. The details of the study have been presented as under:

It may be observed from load-penetration curves that the CBR values of fly ash have been increased significantly on addition of waste sludge.

Amongst all combinations of fly ash-waste sludge mixes, 55%FA+45%S mix exhibits highest CBR value of 9.4% under as compacted condition. Whereas, the lowest CBR value has been observed as 5.8% for the mix 70%FA+30%S under as compacted condition.

The CBR values of the mix improve on curing (Table-8). The most significant effect of curing has been observed in case of 45%FA+55%S mix. The value of CBR at 90 days of curing has been observed as 34.2%. The gain in CBR value of this mix is slow during initial curing periods, it increases significantly on increase in the curing periods. The slow rate of gain of strength might be due to the presence of lime in waste sludge due to which the pozzolanic reaction accelerates in the later stage of curing [31].

4.4. Load Bearing Characteristics of Fly ash-Cement-Waste Sludge Mix

The performance of mix containing fly ash-

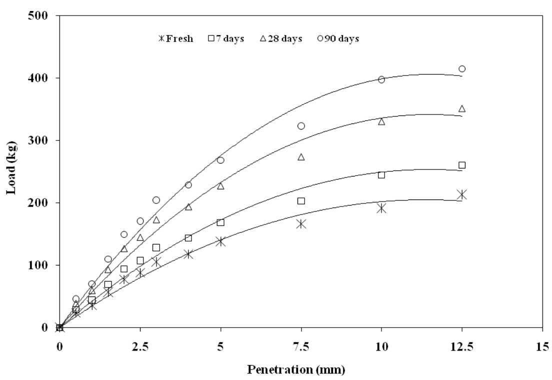


Fig. 6. Load Penetration Curves for 70%FA+30%S Mix

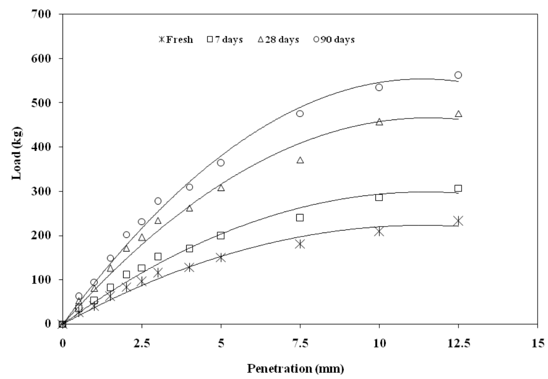


Fig. 7. Load Penetration Curves for 65%FA+35%S Mix

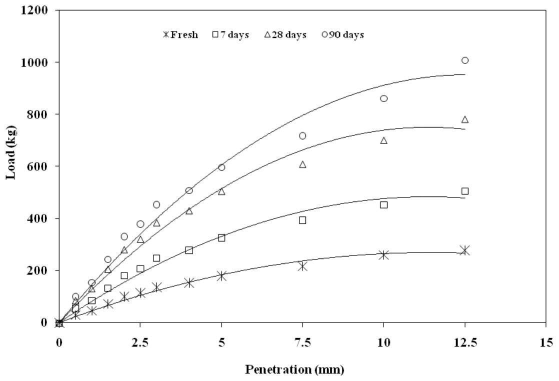


Fig. 8. Load Penetration Curves for 60%FA+40%S Mix

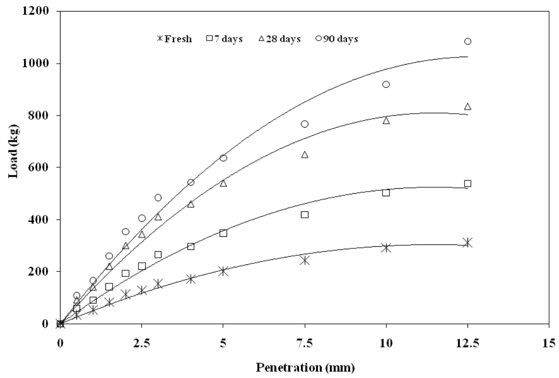


Fig. 9. Load Penetration Curves for 55%FA+45%S Mix

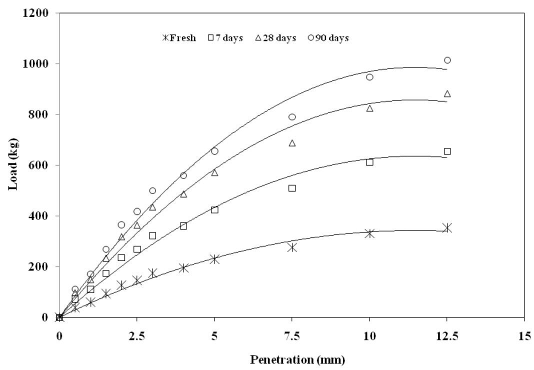


Fig. 10. Load Penetration Curves for 50%FA+50%S Mix

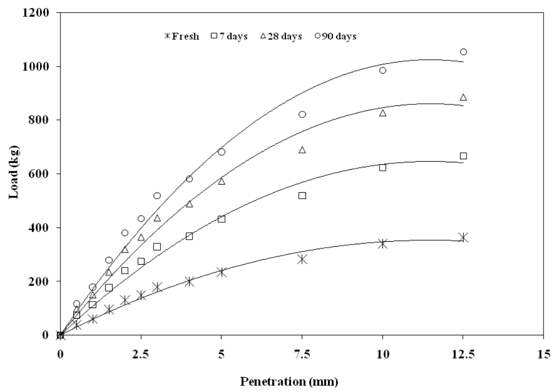


Fig. 11. Load Penetration Curves for 45%FA+55%S Mix

cement-waste sludge have been studied by carrying out CBR tests on specimens prepared with 62%-37%FA, 8%C and 30%-55%S contents under fresh/cured conditions. The results of CBR tests are presented in Figs. 12 to 17 and Tables–7 and 8 to bring out the combined effect of fly ash-cement-waste sludge and curing on CBR values of the mix. The results show that:

The combinations of fly ash-cement-waste sludge exhibit better CBR values than fly ash and fly ash-waste sludge mixes. Amongst all combinations of fly ash-waste sludge-cement, 47%FA+8%C+45%S mix exhibits highest CBR of 10.2% under fresh condition.

The CBR value of mixes improves on curing. The improvement in the CBR has been observed for the mix 42%FA+8%C+50%S at 90 days of curing (Table-8). The CBR value of this mix is 43.7% which is categorized as good subgrade. The gain in CBR value is 498% as compared to fly ash. At 28 days of curing mixes 47%FA+45%S+8%C, 42%FA+50%S+8%C and 37%FA+55%S+8%C exhibit almost equal CBR values. The observed CBR values are 37.9, 38.9 and 37.9% respectively. Due to exhibiting fairly good CBR values, hence, any of the mixes may suitable be used in the construction of pavement.

4.5. Scanning Electron Microscope and XRD for Microstructural Analysis of Stabilized Mix

Figure 18 (a) shows the scanning electron micrographs (SEM) for fly ash. The micrographic observation for fly ash indicates presence of spherical particles in abundance, sub rounded porous grains, irregular agglomerates, opaque spheres and irregular porous grains of unburned carbon.

Figure 18 (b) illustrates the SEM-micrograph of lime precipitated electroplating waste sludge. The micrograph shows an occurrence of detrital grains of silica dust and iron rust fractions and lime as a matrix between the detrital grains. The specimen has been characterized by open fabric

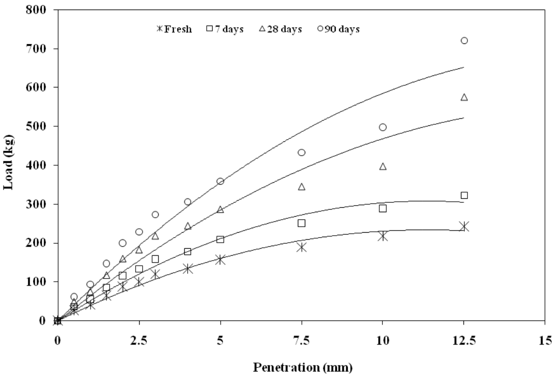


Fig. 12. Load Penetration Curves for 62%FA+30%S+8%C Mix

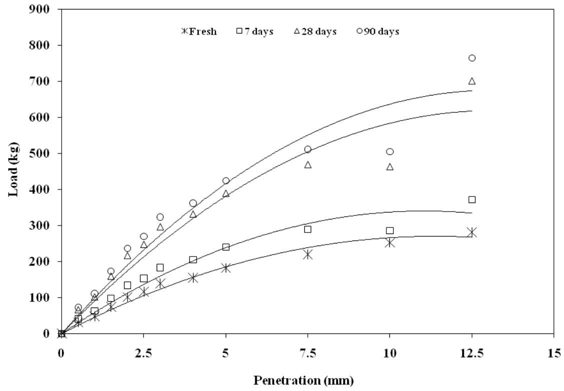


Fig. 13. Load Penetration Curves for 57%FA+35%S+8%C Mix

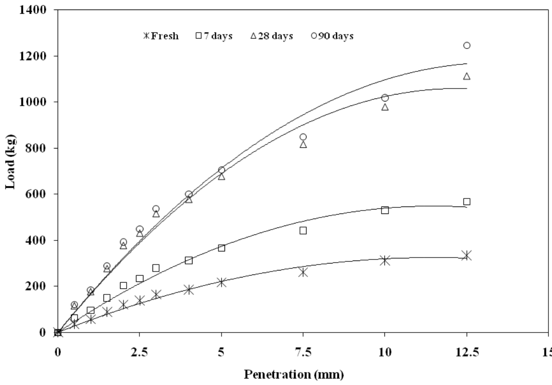


Fig. 14. Load Penetration Curves for 52%FA+40%S+8%C Mix

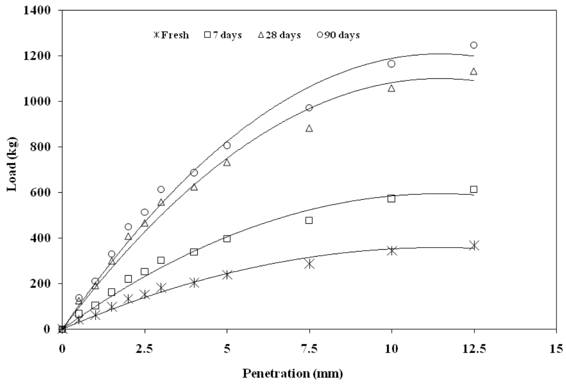


Fig. 15. Load Penetration Curves for 47%FA+45%S+8%C Mix

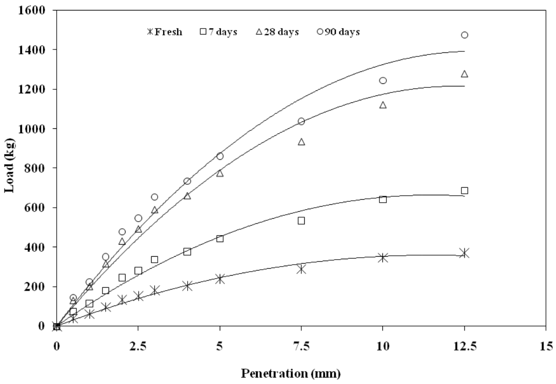


Fig. 16. Load Penetration Curves for 42%FA+50%S+8%C Mix

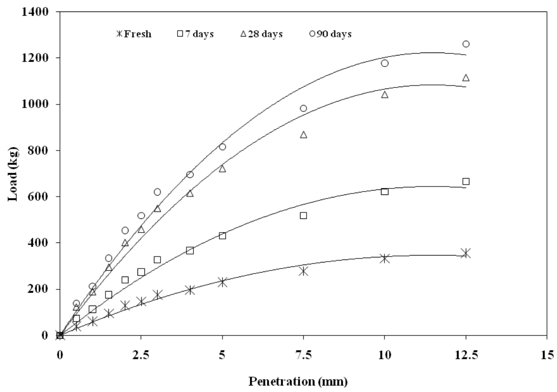
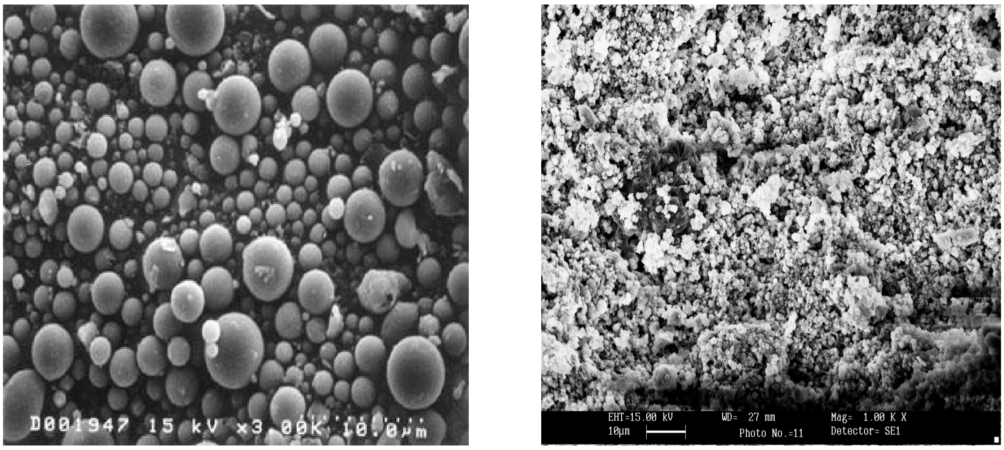


Fig. 17. Load Penetration Curves for 37%FA+55%S+8%C Mix

system and occurrence of relatively large voids distributed in the specimen.

Figure 19 shows a micrograph of 60%FA+40%S mix cured for 90 days. The micrograph illustrates the formation of more new cementitous compounds after long-term curing (spiny crystals) as a result of the pozzolanic reaction coating the aggregates and the fly ash particles and filling the pore spaces (voids) between the flocs. These spiny crystals led to the development of network of reinforcement and to an increase in the strength in the long-term curing. The new cementitous compounds, in the long-term curing, were grown within the pore spaces resulting in a reduction of the radius of the pore spaces.



(a) **(b)**

Fig. 18. Scanning Electron Micrograph (SEM) of (a) Fly ash (b) Lime Precipitated Electroplating Waste Sludge

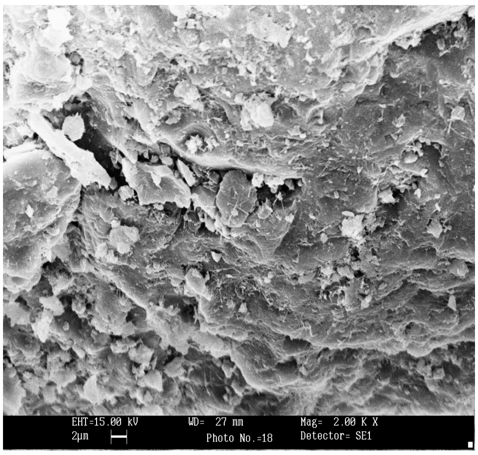


Fig. 19. SEM of 60%FA+40%S

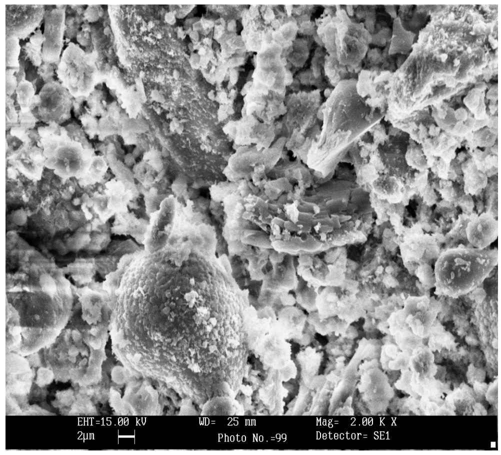


Fig. 20. SEM of 55%FA+45%S

Figure 20 illustrates the microstructural development due to 90 days curing of 55%FA+45%S mix. The micrograph shows a new formation of mineral crystal (as a product of pozzolanic reaction at long-term curing) within the pore spaces. This leads to an increase in the strength gain and a reduction of the radius of the pore spaces and subsequently reducing the drainage. No evidence of ettringite has been found in the tested specimens.

Figure 21 illustrates a micrograph of 47%FA+45%S+8%C mix cured for 28 days. The micrograph shows the hydration reaction product growing on the relics of fly ash particles. Due to presence of lime in the waste sludge and addition cement in the fly ash the pozzolanic reaction products continued to be formed resulting in the better bearing strength. This is confirmation of load penetration curves of this mix.

Figure 22 shows the microstructural development of the mix containing 42%FA+50%S+8%C and cured for 28 days. The micrograph illustrates cementitious compounds (as pozzolanic reaction products) joining together and filling the pore spaces. This led to join fly ash, waste sludge and cement particles together and increase the strength. Subsequently, this contributed to a reduction in porosity of the mix also.

Figures 23and 24 illustrate the needle like microstructure of ettringite, a hydration by-product of tricalcium aluminate in the presence of sulfate ions (which is substantially present in the electroplating waste sludge).

$$\underset{\text{tricalcium aluminate}}{3\,CaO\,Al_2O_3} + \underset{\text{gypsum}}{3\,CaSO_4} + \underset{\text{water}}{32\,H_2O} \rightarrow \underset{\text{ettringite}}{Ca_6Al_2(SO_4)\,3(OH)_{12}\,26\,H_2O}$$

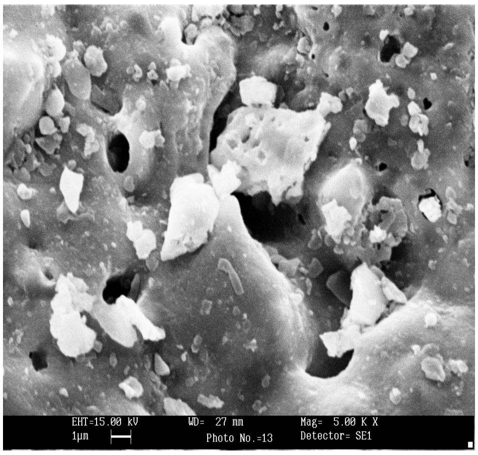


Fig. 21. SEM of 47%FA+45%S+8%C

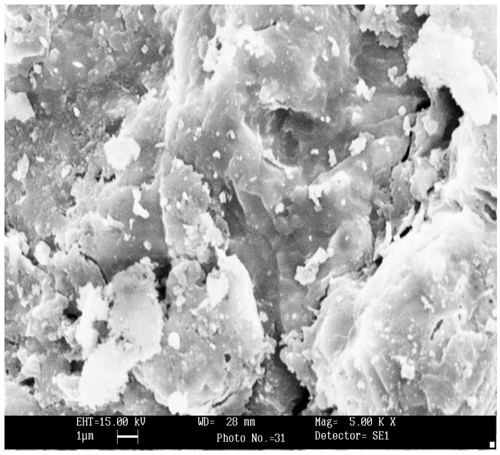


Fig. 22. SEM of 42%FA+50%S+8%C

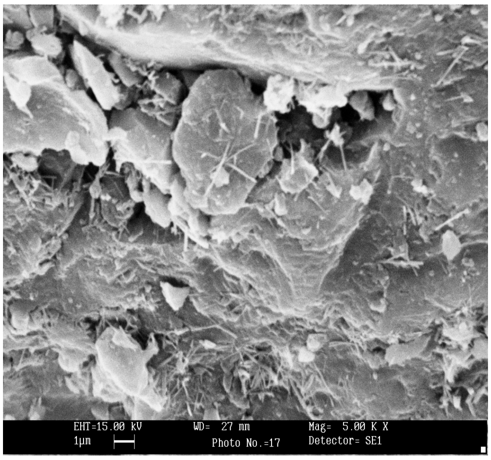


Fig. 23. SEM of 37%FA+55%S+8%C

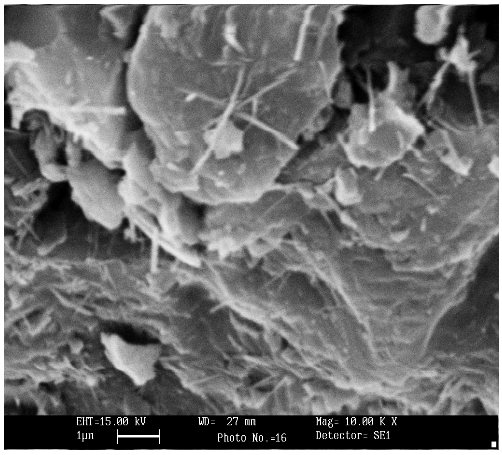
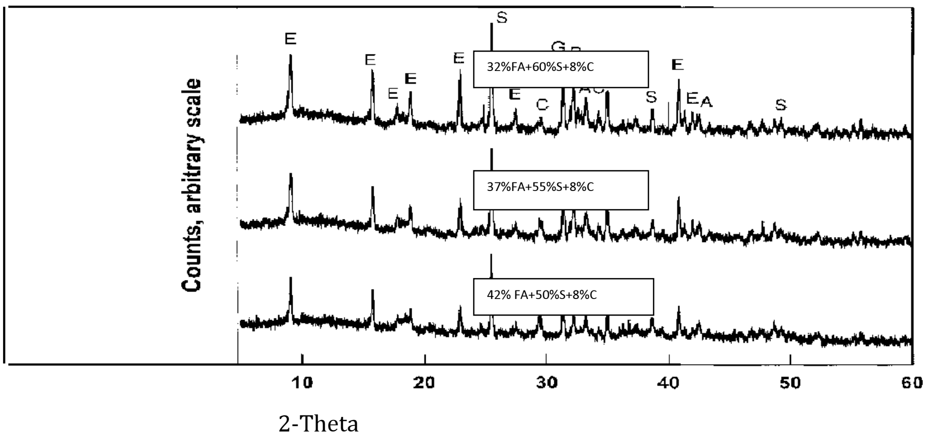


Fig. 24. SEM of 32%FA+60%S+8%C



(A: Al_2O_3; AC: $3CaO{\bullet}Al_2O_3$; B: β -$2CaO{\bullet}SiO_2$; C: $CaCO_3$; E: ettringite; G: $2CaO{\bullet}Al_2O_3{\bullet}SiO_2$; S: $CaSO_4$)
Fig. 25. XRD Pattern of Fly ash-Cement-Waste Sludge Mix at 28 days of Curing

It is well known that this hydration by product can reduce the strength of the solidified matrices as in case of 37%FA+55%S+8%C and 32%FA+8%C+60%S mixes. It is also evident that the ettringite formation is increasing with increase in waste sludge in the mix.

The results of XRD carried out on the most significant specimens (42%FA+8%C+50%S, 37%FA+8%C+55%S and 32%FA+8%C+60%S) cured at 28 days are reported in Fig. 25. It shows the presence of the main $4CaO.3Al_2O_3.SO_3$ hydration product, that $6CaO.Al_2O_3.3SO_3.32H_2O$ (ettringite) in the sample containing more than 50% waste sludge in the mix. It can also be observed that the peaks of the ettringite were increasing with increase in the waste sludge percentage in the mix blend. Due to this reason the strength of the mix blend containing more than 55% waste sludge was decreasing significantly. Therefore, the SEM and XRD analysis confirms the findings of CBR tests.

5. Conclusions

The fly ash of F Class was mixed with 8% cement and 30%-50% waste sludge to attain good strength. The CBR tests were conducted on fresh as well as specimens cured at 7, 28 and 90 days. The following conclusions were drawn from the test results:

The CBR value of freshly compacted fly ash is coming out to be 3.6% which is very low and undesirable for construction. The mix containing 70%-55% fly ash and 30%-45% waste sludge show good bearing strength characteristics.

Addition of small percentage of cement (8%) along with waste sludge to fly ash enhances the bearing strengths at early stage of curing. It has also been observed that the load bearing strengths of fly ash were increased to manifolds on addition of waste sludge and cement to it.

Fly ash mixed with 8% cement and 50% waste sludge has achieved CBR value of 43.7% at 90 days of curing. The gain in CBR value of fly ash after addition of 8% cement and 50% waste sludge is 350% at 90 days of curing.

Thus, fly ash mixed with cement and waste sludge may find potential applications in road and embankment constructions due to its strength characteristics, durability, longevity and environmental safety which were ensured by TCLP leaching test.

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