LONG TERM ASSESSMENT OF STRENGTH AND HEAVY METAL CONCENTRATION IN CEMENT-FLY ASH STABILIZED ELECTROPLATING WASTE SLUDGE

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Abstract: The main objective of this study is to utilize the locally available industrial wastes materials like fly ash (FA) and electroplating wastes (S) in bulk for the Civil Engineering works and replacement of weak sub grade soil by stabilizing the fly ash using electroplating waste and other additives like cement (C). The compressive strength tests of the mix containing varying percentages (by weight of fly ash) of electroplating waste sludge (5–60% with an increment of 5%) and of fly ash-waste sludge-cement have been determined for different curing periods. It has been observed that the significant gain in compressive strength exhibited for waste range 30% to 45%. The percentage increase in 28 days compressive strength for mix containing waste sludge 30—40%, 62—52% fly ash and 8% cement is 36% while for 30% and 45% waste sludge, 70% and 55% fly ash and 8% cement is 13%. The Toxicity Characteristics Leaching Procedure (TCLP) tests were also conducted to determine the heavy metal concentration in the optimized mix. The results of TCLP test show that the heavy metal concentration in the mix 52%FA+40%S+8%S at 28 days of curing reduced substantially from 97 to 100% when compared with the concentration of heavy metals in the waste sludge collected from source. It has also been observed that the pH of the leachate of this mix is between 6.9-10.9, which ensures the proper stabilization of the heavy metals present in the mix.

Keywords: *Fly ash, electroplating waste, cement, compressive strength, leaching,*

1.0 Introduction

Safe and economic disposal of industrial waste including coal ash from thermal power plants continues to remain a cause of concern to the industrial societies. Alternative use of these waste products in civil engineering applications extensively researched and widely adopted in Continental, Europe and America. Now, it is steadily being realized in developing countries including India. The thermal power stations in India at present generate nearly 200 million tons of coal ash every year, out of which only about 15% is presently utilized in cement, concrete, bricks and geotechnical and highway engineering applications. The high ash content of Indian coal (30–50%) is contributing to these large volumes of fly ash. As a general practice in India, fly ash are mixed with water and transported to ash ponds. The fly ash collected in these ponds cause severe respiratory and other ailments, visual and aesthetic problems in almost all the major industrial cities in India. On the other hand one of the major hazardous waste generating industries is the electroplating industry due to the presence of high concentration of heavy metals such as Nickel (Ni), Chromium (Cr), Lead (Pb), Copper (Cu), Cadmium (Cd) and Zinc (Zn) etc., (Chang *et al.*, 1999).

As the restrictions on land filling become stronger and wastes were banned from land disposal. Solidification/stabilization (S/S) could potentially play an important role in making wastes acceptable for land disposal. This has attracted the attention of many researchers to stabilize the waste sludge containing heavy metals using fly ash and cement. The solidification/stabilization (S/S) process can be used to encapsulate the wastes by adsorption, hydration or precipitation reactions with cement and water (Gitari *et al.*, 2010 and Wu *et al.*, 2012). The results of these interactions are the stabled forms of waste which are non-hazardous or less hazardous than raw material (Zheng *et al.*, 2010, Maschio *et al.*, 2011 and Colangelo *et al.*, 2012). These studies showed that the waste sludge containing heavy metals, when stabilized with fly ash and cement, the mix exhibits acceptable compressive strength and good leaching resistance. Before the landfill, which is the most popular constituent of waste storage, the environmental characterization i.e., leaching test is required on crushed mortar samples. The leaching tests were used in many applications, ranging from the classification of industrial wastes for disposal in landfills to assess the stability of solid wastes for their beneficial use. Failure to pass a leaching test requires the waste to be treated where the contaminants in the waste were immobilized by stabilization/solidification procedures prior to its disposal.

Fly ash and cement stabilization is one of the examples of such treatment. The leaching of heavy metals from cementitious waste has been investigated in many studies (Poon *et al.*, 2001 and Halim *et al.*, 2003). The main findings of these studies were that the cementitious wastes have a high acid neutralizing capacity (ANC) which tends to quickly neutralize the acidity of the toxicity characteristics leaching procedure (TCLP) leaching fluid (acetic acid). It is suggested that the pH is the most important factor to be observed during the leaching process as it influences the speciation and solubility of metals in the system (Aubert *et al.*, 2007 and Cetin *et al.*, 2012). Therefore, keeping in view the long term environmental acceptability of the mix containing fly ash, waste sludge and cement, the present investigation is carried out. This study serves two purposes such as it immobilizes the toxic heavy metals and at the same time utilizes the two industrial wastes such as fly ash and electroplating waste sludge for mass scale utilization.

2.0 Materials and Methods

2.1 Materials

In this study, the materials used are fly ash**,** electroplating waste sludge**,** lime and cement.

2.1.1 Fly Ash

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 (Fly ash Status Summary, 2005). For the present investigation, dry fly ash from hoppers is collected in polythene bags.

2.1.2 Physical Properties of Fly ash

The physical properties of fly ash is shown in Table 1. The fly ash used in the present study can be classified as ML (silt of low compressibility) as per IS: 1498-1987.

Table 1: Physical Properties of Fly ash

Constituent/Property	**Value**
Colour	Grey
Percent passing 75 μ sieve	82%
Size of the particle	0.002-0.30mm
Maximum dry density (MDD)	9.00 kN/m^3
Optimum moisture content (OMC)	23%
Surface area	2893cm^2/g
Unburnt carbon	15.60%

2.1.3 Chemical Composition of Fly Ash

The chemical composition of fly ash is shown in Table 2.

Table 2: Chemical Properties Fly ash

Constituent/Property	**Value**
SiO_2	59%
Al_2O_3	27%
Fe_2O_3	5%
CaO	3%
MgO	4%

2.2 Electroplating Waste Sludge

The electroplating waste sludge was collected in the form of filter cake, comprises of 70% solid waste and 30% waste water. The solid waste includes chemicals, heavy metals and metallic dust. Heavy metal analysis was carried out using GBC-902 atomic absorption spectrophotometer (AAS). The AAS observation shows that the quantity of heavy metals in the electroplating waste sludge was extremely high as shown in Table 5.

2.2.1 Physical Properties

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

Table 3 : Physical Properties of Electroplating Waste Sludge

Constituent/Property	**Value**
Total Solids	105340mg/l
Total dissolved solids	7315mg/l
Total suspended solids	132738mg/l
Specific gravity	1.090
pH	1.5<2 (hazardous)

2.2.2 Chemical Properties

The chemical composition and heavy metal concentration are shown in Tables 4 & 5.

Table 4: Chemical Compositions of Electroplating Waste Sludge

Chemical	**Concentration(mg/l)**
Nickel Sulfate ($NiSO_4.6H_2O$)	225-375
Nickel Chloride ($NiCl_2.6H_2O$)	30-60
Boric acid (H_3BO_3)	30-40
Sodium Hydroxide (NaOH)	80-120
Sodium Cyanide (NaCN)	15-25
Potassium Chloride(KCl)	120-150
Sodium Sulfide (Na_2S)	200
Chromic Acid (H_2CrO_4)	250-300
Sulfate (SO_4)	2.5- 5.0

Table 5 : Heavy Metal Concentrations in Electroplating Waste Sludge

Metals	**Concentration (mg/l or ppm)**	**Desirable limits for drinking water (mg/l or ppm)**
Nickel (Ni)	98	3.0
Chromium (Cr)	27	0.1
Zinc (Zn)	30	5.0
Cadmium (Cd)	12	2.0
Copper (Cu)	07	3.0
Lead (Pb)	4.5	0.1

2.3 Lime

The finely powered white coloured lime was used as precipitator having the chemical composition given in Table 6.

Table 6 : Composition of Lime

Constituent/Property	**Value**
Assay	95%
Chloride (Cl)	0.01%
Sulfate (SO_4)	0.2%
Aluminum, iron and insoluble matters	1.0%
Arsenic (As)	0.0004%
Lead (Pb)	0.001%

2.4 Cement

The cement used in this study was OPC JP-43 grade. The test on cement was conducted in accordance with IS: 269 (1989). The physical and chemical properties of cement are given in Tables 7 & 8.

Table 7 : Physical Properties of OPC JP-43 Grade Cement

Constituent/Property	**Value**
Specific surface cm^2/gm	3175
Soundness in mm	3.30
Compressive strength in kg/cm^2 at 3 days	143
On 1:3 cement sand mortar at 7 days	235
Setting time in minutes Initial Final	 100 290
Specific gravity	3.13
Normal consistency (water in % of cement by weight)	27.5

Table 8 : Chemical Composition of Cement

Constituent/Property	**Value (%)**
Total loss on ignition % by weight	0.89
Weight of insoluble residue % by weight	1.17
Silica (SiO_2)	17–25
Calcium Oxide (CaO)	60–70
Magnesium Oxide (MgO)	0.1–4
Ferric Oxide (Fe_2O_3)	0.5–6
Alumina (Al_2O_3	3–8
Sulfur trioxide (SO_3)	1–3

3.0 Preparation and Testing of Specimens

The preparation and testing of specimens for compressive strength tests have been carried out in accordance with the IS: 4031 (Part 6).

Fly ash and lime precipitated electroplating waste sludge was dried in oven for 24 hours and sieved through 0.425 mm IS sieve. The standard Proctor compaction test was carried out using the equipment and procedure as specified in IS: 2720 (Part 7)-1987 to obtain maximum dry density (MDD) and optimum moisture content (OMC) of the mix. The average value of OMC of the mix (fly ash-waste sludge-cement) was obtained as 22% which is further used for preparing the cube specimens. The desired amount of fly ash-waste sludge-cement was taken and mixed them thoroughly in dry condition. The water equal to 22% was added to the dry mix and mixed it to obtain a mix of uniform colour. The mould was filled with desired quantity of mix using a suitable hopper attached to the top of the mould and vibrated it for 2 minutes at a specified speed of 12000±400 per minute to achieve full compaction. The mould was removed from the machine and kept it in a place with temp of 27 ± 2^0C and relative humidity of 90% for 24 hours. At the end of 24 hours the cubes were de-molded and immediately submerged in fresh clean water. All the cubes were prepared with the different combinations shown in Table 9 by repeating the same procedure.

Place the test cube on the platform of a compressive testing machine without any packing between the cube and the plates of the testing machine. Apply the load steadily and uniformly, starting from zero at a rate of 35 N/mm^2/minute.

Toxicity Characteristics Leaching Procedure (TCLP) is the US Environmental Protection Agency (US EPA) procedure for assessing the potential for hazardous wastes to leach in the ground water from a landfill (US EPA, 1992). As described in the TCLP procedure, the molded cubes of different curing periods (Table 9) were crushed to particles less than 1 mm in diameter and then blended with a weak acetic acid extraction liquid, in liquid to solid weight ratio of 20:1 and was agitated in a rotary extractor for a period of 18 hours of agitation. The extract was filtered through a certified TCLP 0.7µ borosilicate glass fibre filter, and the filterate was analyzed for Ni, Cr, Zn, Cd, Cu and Pb by using GBC-902 Atomic Absorption Spectrophotometer (AAS).

Table 9 : Details of Various Test Conditions

Mix	**Compressive Strength Test**	**TCLP (Leaching Test)**
Fly ash (FA)	7, 14, 21, 28, 90 and 365 days	-
95%FA+05%S	7, 14, 21, 28, 90 and 365 days	-
90%FA+10%S	7, 14, 21, 28, 90 and 365 days	-
85%FA+15%S	7, 14, 21, 28, 90 and 365 days	-
80%FA+20%S	7, 14, 21, 28, 90 and 365 days	-
75%FA+25%S	7, 14, 21, 28, 90 and 365 days	-
70%FA+30%S	7, 14, 21, 28, 90 and 365 days	-
65%FA+35%S	7, 14, 21, 28, 90 and 365 days	-
60%FA+40%S	7, 14, 21, 28, 90 and 365 days	-
55%FA+45%S	7, 14, 21, 28, 90 and 365 days	-
50%FA+50%S	7, 14, 21, 28, 90 and 365 days	-
45%FA+55%S	7, 14, 21, 28, 90 and 365 days	-
40%FA+60%S	7, 14, 21, 28, 90 and 365 days	-
98%FA+02%C	7, 14, 21, 28, 90 and 365 days	-
96%FA+04%C	7, 14, 21, 28, 90 and 365 days	-
94%FA+06%C	7, 14, 21, 28, 90 and 365 days	-
92%FA+08%C	7, 14, 21, 28, 90 and 365 days	-
90%FA+10%C	7, 14, 21, 28, 90 and 365 days	-
88%FA+12%C	7, 14, 21, 28, 90 and 365 days	-
86%FA+14%C	7, 14, 21, 28, 90 and 365 days	-
84%FA+16%C	7, 14, 21, 28, 90 and 365 days	-
82% FA+18% C	7, 14, 21, 28, 90 and 365 days	-
80%FA+20%C	7, 14, 21, 28, 90 and 365 days	-
93-75%FA+2-20%C+05%S	7, 14, 21, 28, 90 and 365 days	-
88-70%FA+2-20%C+10%S	7, 14, 21, 28, 90 and 365 days	-
83-65%FA+2-20%C+15%S	7, 14, 21, 28, 90 and 365 days	-
78-60%FA+2-20%C+20%S	7, 14, 21, 28, 90 and 365 days	-
73-55%FA+2-20%C+25%S	7, 14, 21, 28, 90 and 365 days	-
68-50%FA+2-20%C+30%S	7, 14, 21, 28, 90 and 365 days	28-365 days with a step of 1 month
63-45%FA+2-20%C+35%S	7, 14, 21, 28, 90 and 365 days	28-365 days with a step of 1 month
58-40%FA+2-20%C+40%S	7, 14, 21, 28, 90 and 365 days	28-365 days with a step of 1 month
53-35%FA+2-20%C+45%S	7, 14, 21, 28, 90 and 365 days	28-365 days with a step of 1 month
48-30%FA+2-20%C+50%S	7, 14, 21, 28, 90 and 365 days	28-365 days with a step of 1 month
43-25%FA+2-20%C+55%S	7, 14, 21, 28, 90 and 365 days	28-365 days with a step of 1 month
38-20%FA+2-20%C+60%S	7, 14, 21, 28, 90 and 365 days	28-365 days with a step of 1 month

4.0 Results and Discussion

4.1 Compressive Strength of Fly Ash Mixed with Electroplating Waste

The compressive strength tests of the mix containing varying percentages of electroplating waste sludge (5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55% and 60%) and fly ash were carried out and the results are shown in Figure 1. It has been observed that the strength of mix is affected by waste sludge percentages and curing periods. The gain in the compressive strength has been observed on increasing the waste sludge percentage in the fly ash. However, it may also be observed that the increase in the compressive strength is upto 45% of waste sludge in fly ash, thereafter, strength decreases. The increase in the strength of the mix upto certain percentage of waste sludge in the fly ash might be due to presence of lime used for precipitation as well as presence of metallic dust in the waste sludge, which is acting as a reinforcing agent. However, on addition of waste sludge to fly ash beyond 45% the decrease in compressive strength can be observed, which is might be due to presence of sulphate, chloride and boric acid etc., present in the mix. Sulfate attack will cause expansion, cracking or spalling or softening and disintegration. The expansion which is as a result of the increase in the solid volume is caused by the conversion of calcium hydroxide to gypsum and then also by the conversion of the hydrated calcium aluminate with gypsum to calcium sulfoaluminate (Eglinton, 1987, Shah and Hookham, 1998). The softening and disintegration is specifically due to the attack by magnesium sulfate as mentioned earlier and leads to strength loss and cracking.

The result of compressive strength test of optimized mix 55%FA+45%S is shown in Table 10. The maximum compressive strength of this mix at 14, 28, 90 and 365 days of curing were 15, 17.5, 19 and 21 MPa respectively. It has also been observed that the compressive strength increases with increase in curing, but the significant gain in strength can be observed for this combination after 14 days onwards. The percent increase in strength at 14, 21, 28, 90 and 365 days of curing with respect to 7 days are 100, 113, 133, 153 and 180%. This indicates that the gain in the strength continues with curing but, most of the strengths were achieved after 14 days curing.

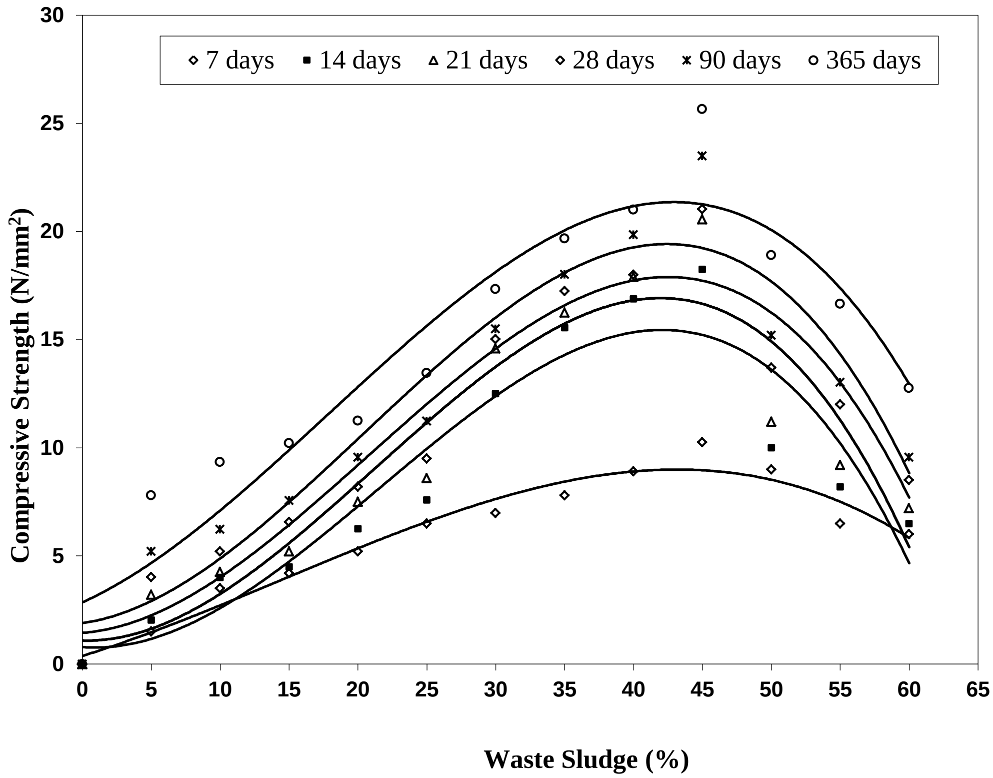


Figure 1 : Plain Fly ash (FA) with Waste Sludge (S)

Table 10 : Variation of Optimized Mix with Curing Period

Waste (%)	**Curing (days)**					
	7	**14**	**21**	**28**	**90**	**365**
Compressive Strength of 55%FA+45%S mix (MPa)	7.5	15.0	16.0	17.5	19.0	21.0
Increase in Strength of mix 55%FA+45%S with 7 days of curing	-	100	113	133	153	180

4.2 Compressive Strength of Fly Ash Mixed with Cement

Cement in varying percentages by weight of fly ash (2–20% with an increment of 2%) was added as an additive to the fly ash. The results are presented in Figure 2 shows that by increasing the cement percentage, compressive strength of fly ash-cement mix also increases but the significant increase in strength was observed from 8.2 MPa at 6% cement to 12 MPa at 8% cement at 7 days curing, while at 20% cement the compressive strength was observed as 20 MPa for 7 days curing. On the other hand the compressive strength for 8% and 20% cement at 28 days of curing has been observed as 15.1 MPa and 27 MPa respectively. Therefore, for economical considerations the optimum percentages of cement may be considered as 8% for further studies.

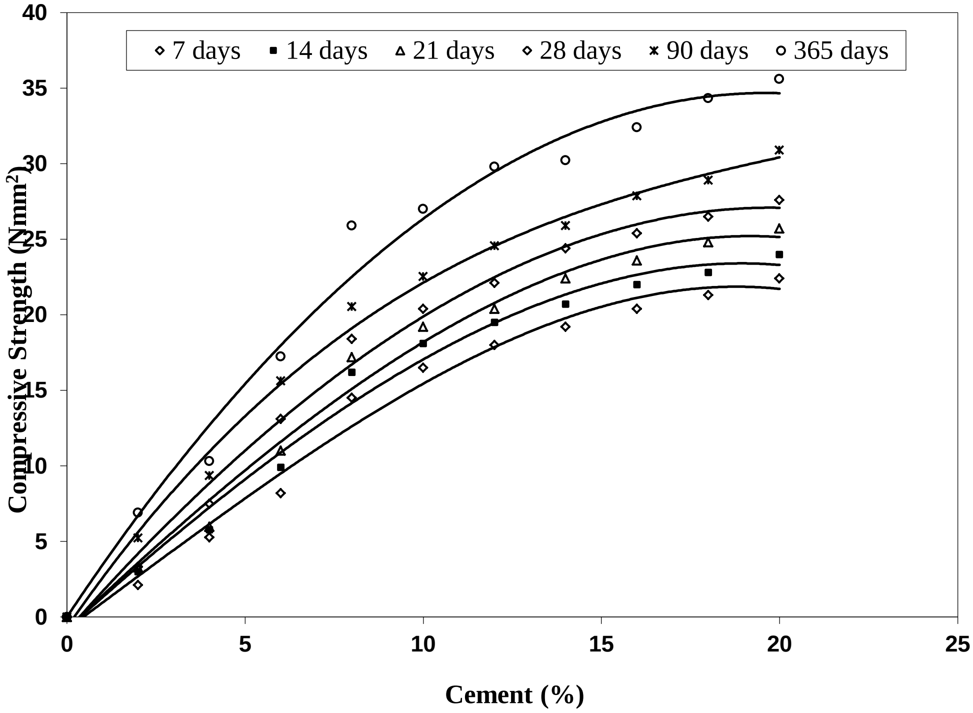


Figure 2 : Plain Fly ash with Cement

4.3 Compressive Strength of Fly Ash Mixed with Electroplating Waste and Cement

The compressive strength tests of mix containing varying percentages of electroplating waste sludge (5% and 30–60% with an increment of 5%) and cement varying from 2% to 20% with a step of 2% were carried out, and the results are plotted in Figs. (3 to 10). From Figure 3 it has been observed that for 87%FA+8%C+5%S mix the values of compressive strength at 7, 14, 21, 28, 90 and 365 days of curing are 11.97, 16.5, 17.7, 17.9 and 19.23 MPa respectively, which are almost equal to the compressive strength of 92%FA+8%C (14.5, 16.2, 17.2, 18.4, 20.53 MPa respectively) and the same trend in compressive strength values are found for 90%FA+10%S, 85%FA+15%S, 80%FA+20%S and 75%FA+25%S mixes (Figure 2).

It has also been observed that the significant gain in strength exhibited for waste range 30% to 45%. The percentage increase in 28 days compressive strength for mix containing waste sludge 30% and 40%, 62% and 52% fly ash and 8% cement is 36%

while for 30% and 45% waste sludge, 70% and 55% fly ash and 8% cement is 13%, therefore, the optimum percentage of waste sludge may be adopted between 30% to 40% in general and 40% in particular. It can also be observed that the strength is remarkably increasing with increase in curing. For 62%FA+8%C+30%S the percentage increase in the strength at 7 days to 365 days curing is 66%. For 52%FA+8%C+40%S the increase is 87% and 47%FA+8%C+45%S it is about 81%. Hence, it may be concluded that the optimum waste sludge percentage may be in the range of 30% to 40% and 8% cement.

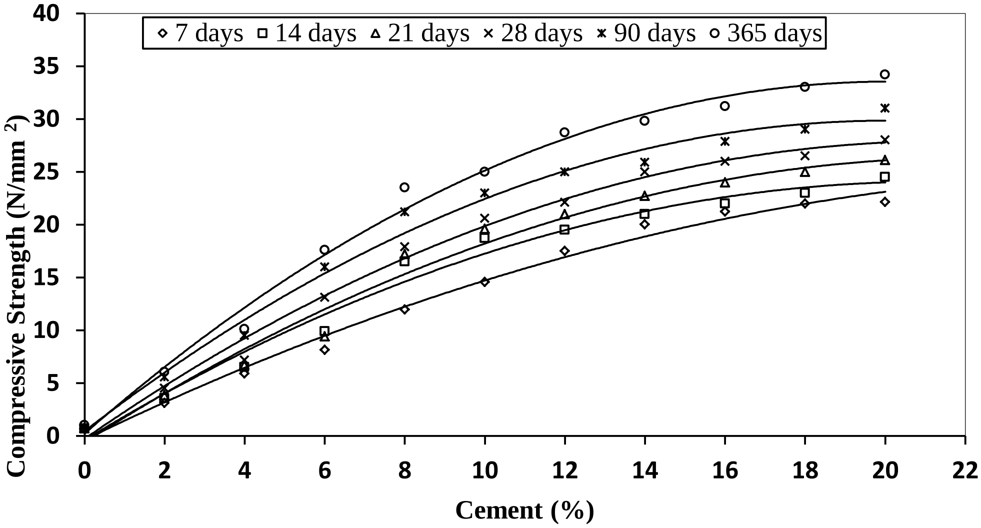


Figure 3 : FA+05%S with Cement

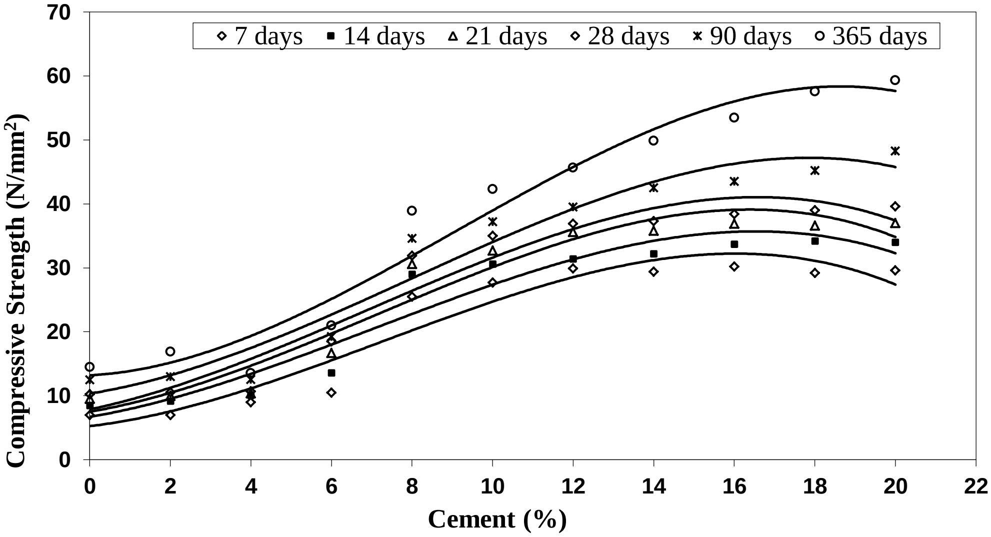


Figure 4 : FA+30%S with Cement

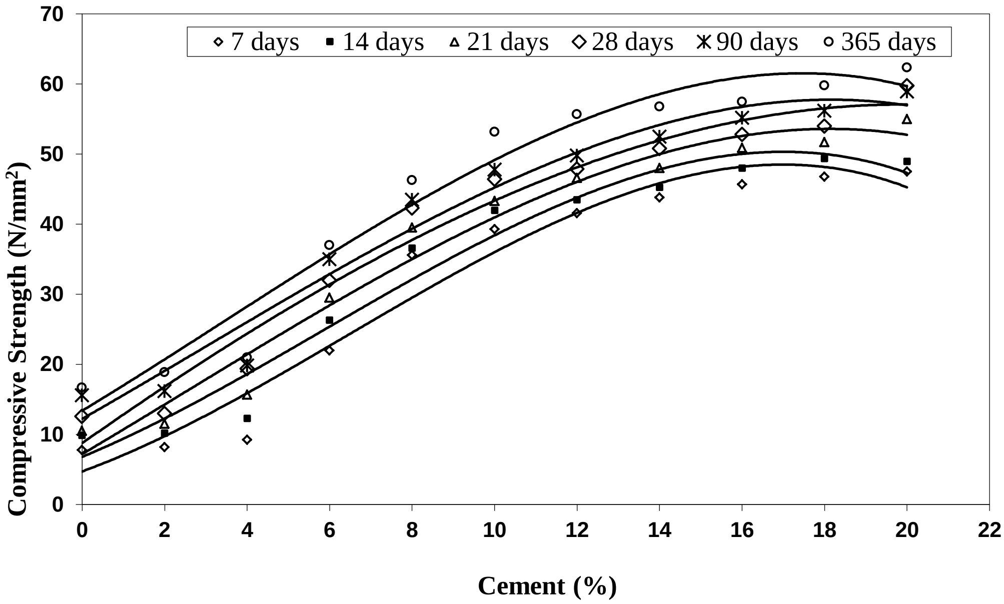


Figure 5 : FA+35%S with Cement

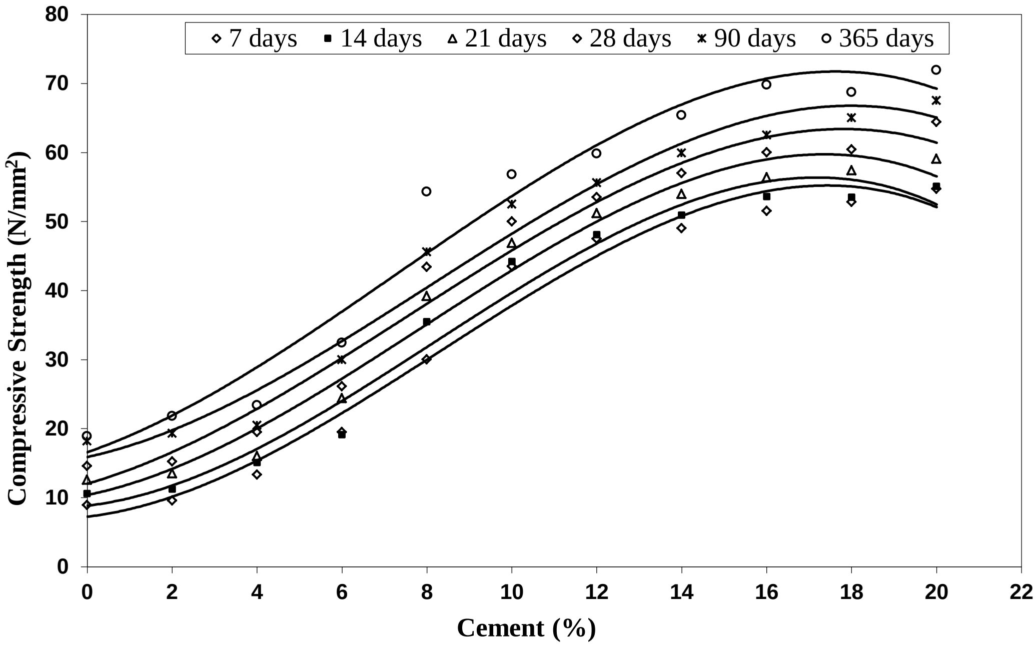


Figure 6 : FA+40%S with Cement

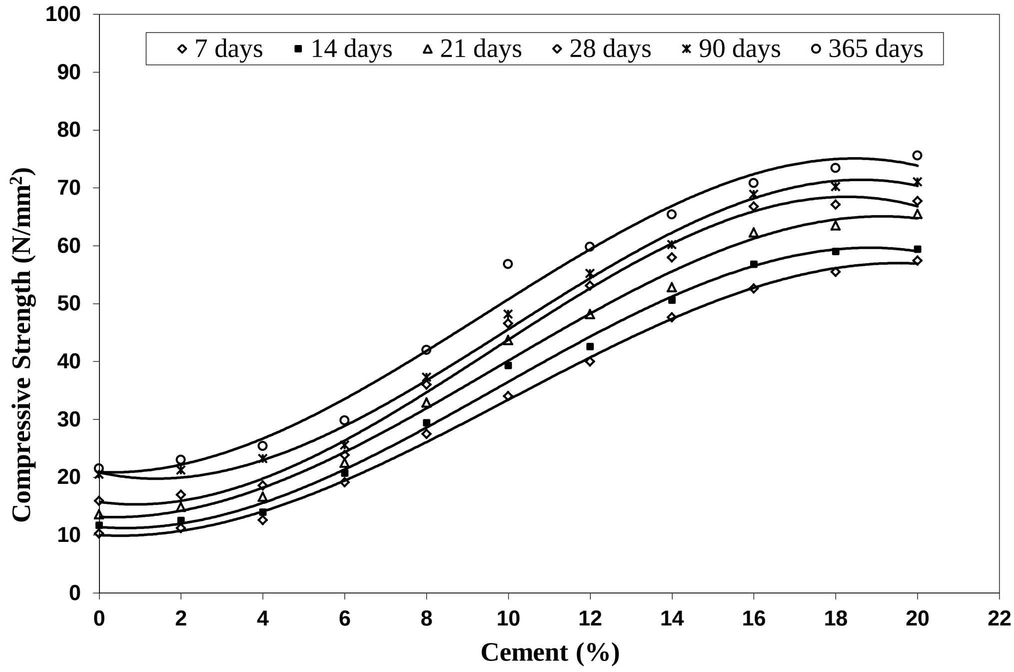


Figure 7 : FA+45%S with Cement

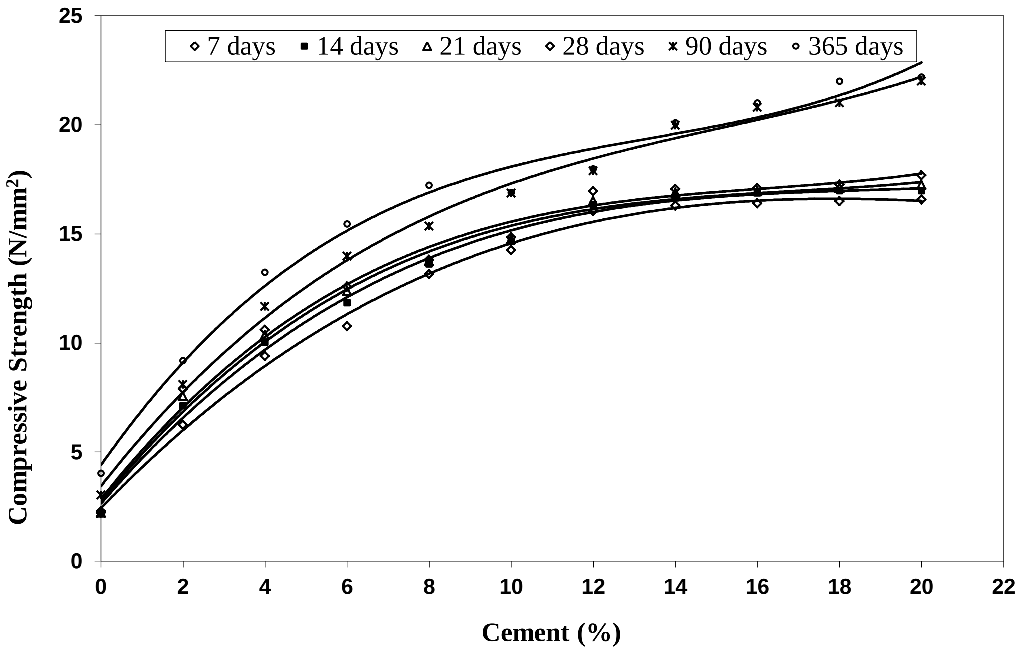


Figure 8 : FA+50%S with Cement

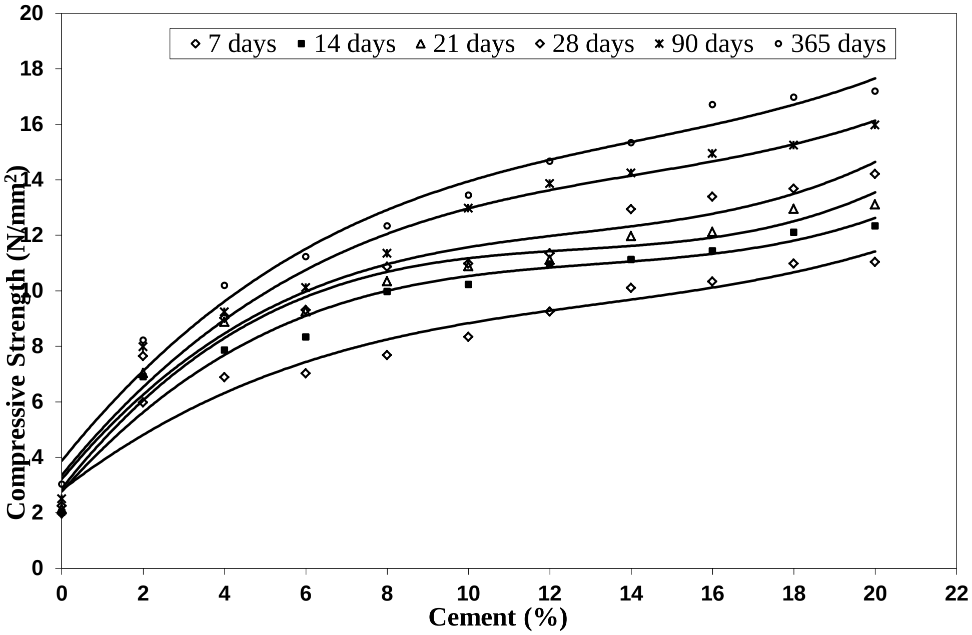


Figure 9 : FA+55%S with Cement

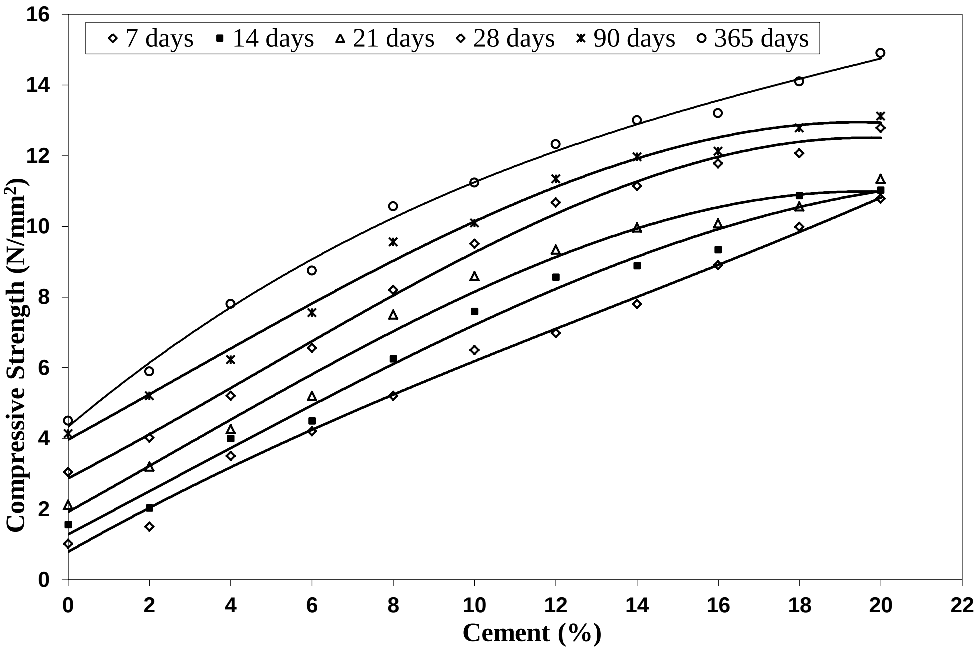


Figure 10 : FA+60%S with Cement

The comparison of the 28 days compressive strength of present and previous studies (Weng and Huang, 1994 and Sophia & Swaminathan, 2005) of fly ash-cement stabilized metal waste sludge are presented in Table 11. The comparison clearly shows that the strength of the cement stabilized metal-laden fly ash matrix is superior to that of cement stabilized metal waste sludge. To produce more strength of waste sludge-cement binder, additional treatment of the waste sludge may be necessary, as it is observed from the present study. When waste sludge was precipitated with 10% lime, the strength ratios were found substantially higher than the reference specimen (92%FA+08%C). The mix (52%FA+8%C+40%S) gives strength ratio as (2.13) which is much higher than the reference specimen (1.0). Table 11 further showed that the strength of the mix was decreasing with an increase in the plating waste sludge percentage which is in contrast with the present study. However, the findings of the present study are similar to the study carried out by Cioffi *et al.*, 2002. The author has suggested that when waste sludge was treated with lime its strength increases up to certain extent.

4.4 Scanning Electron Microscope for Microstructural Analysis of Stabilized Mix

4.4.1 Scanning Electron Micrograph (SEM) of Fly Ash

Figure 11 (a) shows the Scanning Electron Micrograph (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.

4.4.2 Scanning Electron Micrograph (SEM) of Lime Precipitated Waste Sludge

Figure 11 (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 system and occurrence of relatively large voids distributed in the specimen.

4.4.3 Scanning Electron Micrograph (SEM) of 60%FA+40%S Mix at 28 days of Curing

Figure 12 shows a micrograph of 60%FA+40%S mix cured for 28 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.

4.4.4 Scanning Electron Micrograph (SEM) of 60%FA+40%S Mix at 365 Days of Curing

Figure 13 illustrates the microstructural development due to 365 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.

4.4.5 Scanning Electron Micrograph (SEM) of 52%FA+40%S+8%C Mix at 365 Days of Curing

Figure 14 illustrates a micrograph of 52%FA+40%S+8%C mix cured for 365 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.

4.4.6 Scanning Electron Micrograph (SEM) of 47%FA+45%S+8%C Mix at 365 Days of Curing

Figure 15 shows the microstructural development of the mix containing 47%FA+45%S+8%C and cured for 365 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.

4.4.7 Scanning Electron Micrograph (SEM) of 42%FA+50%S+8%C and 37%FA+55%S+8%C Mixes at 365 Days of Curing

Figures 16 and 17 illustrate the needle like microstructure of ettringite, a hydration by-product of tricalcium aluminate in the presence of sulfate ions, shown in following equation (which is substantially present in the electroplating waste sludge).

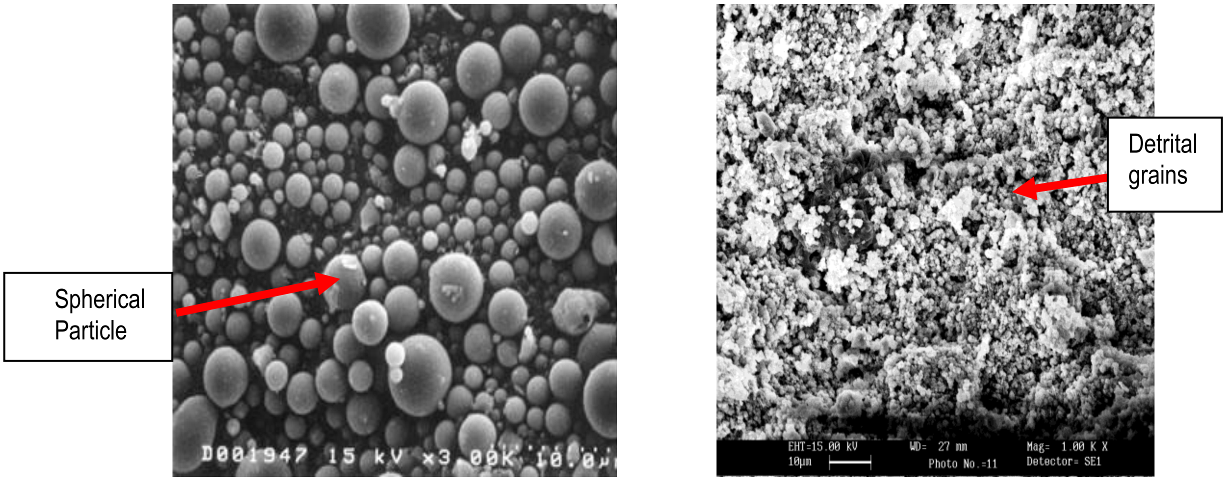
$$\underbrace{3CaO\ Al_2O_3}_{\text{tricalcium aluminate}} + \underbrace{3CaSO_4}_{\text{gypsum}} + \underbrace{32H_2O}_{\text{water}} \rightarrow \underbrace{Ca_6Al_2(SO_4)3(OH)_{12}\ 26H_2O}_{\text{ettringite}} \quad (1)$$

It is well known that this hydration by product can reduce the strength of the solidified matrices as in case of 42%FA+50%S+8%C and 37%FA+55%S+8%C mixes. It is also evident that the ettringite formation is increasing with increase in waste sludge in the mix.

Table 11 : Comparison of 28 days Compressive Strength of Various Metal Waste Sludges Stabilized by Fly ash and Cement

Matrix	**W / (C+F)[a]**	**Strength (N/mm^2)**	**Strength Ratio[b]**	**Source**
Cement (reference specimen)	0.50	35.5	1.00	Claudio and Sobrinho (1990)[c]
Cement+metal+waste sludge	0.50	1.4	0.04	Claudio and Sobrinho (1990)[c]
Cement (reference specimen)	0.50	41.1	1.00	Tay (1987)
Cement+10% waste sludge	0.50	41.0	1.00	Tay (1987)
Cement (reference specimen)	0.45	24.4	1.00	Weng and Huang (1994)
Cement+10% Cd laden fly ash	0.45	21.3	0.87	Weng and Huang (1994)
Cement+10% Zn laden fly ash	0.45	21.3	0.87	Weng and Huang (1994)
Cement+10% fly ash	0.45	22.5	0.92	Weng and Huang (1994)
Cement (reference specimen)	0.38	25.0	1.00	Sophia and Swaminathan (2005)
60%S+30%C+10%FA	0.38	06.0	0.24	Sophia and Swaminathan (2005)
60%S+10%C+30%FA	0.38	05.0	0.20	Sophia and Swaminathan (2005)
70%S+20%C+10%FA	0.38	04.0	0.16	Sophia and Swaminathan (2005)
70%S+10%C+20%FA	0.38	03.0	0.12	Sophia and Swaminathan (2005)
80%S+10%C+10%FA	0.38	02.0	0.08	Sophia and Swaminathan (2005)
90%S+05%C+05%FA	0.38	01.0	0.04	Sophia and Swaminathan (2005)
92%FA+8%C(reference specimen)	0.65	18.40	1.00	Present study
70%FA+30%S	0.30	15.00	0.82	Present study
65%FA+35%S	0.35	17.00	0.92	Present study
60%FA+40%S	0.40	18.00	0.98	Present study
55%FA+45%S	0.45	18.50	1.01	Present study
50%FA+50%S	0.50	16.70	0.91	Present study
45%FA+55%S	0.55	16.00	0.87	Present study
40%FA+60%S	0.60	08.50	0.47	Present study
87%FA+8%C+05%S	0.05	17.90	0.99	Present study
62%FA+8%C+30%S	0.42	26.90	1.46	Present study
57%FA+8%C+35%S	0.53	36.60	1.99	Present study
52%FA+8%C+40%S	0.66	39.20	2.13	Present study
47%FA+8%C+45%S	0.81	36.00	2.00	Present study
42%FA+8%C+50%S	1.00	13.80	0.76	Present study
37%FA+8%C+55%S	1.22	10.87	0.60	Present study
32%FA+8%C+60%S	1.50	08.20	0.45	Present study

[a]*Water-to-binder ratio*
[b]*With respect to that of reference specimen*
[c]*Brazil portland cement and cylinder molds 3.3 cm in diameter and 1 cm long were used waste sludges were obtained from electroplating treatment plant*



(a) **(b)**

Figure 11 : Scanning Electron Micrograph (SEM) of (a) Fly ash
(b) Lime Precipitated Electroplating Waste Sludge

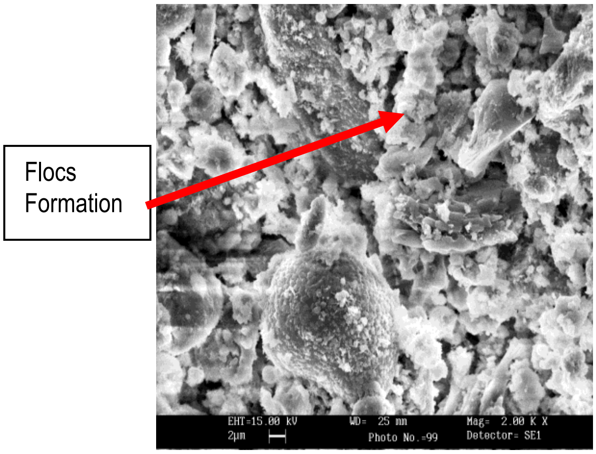


Figure 12: SEM of 60%FA+40%S

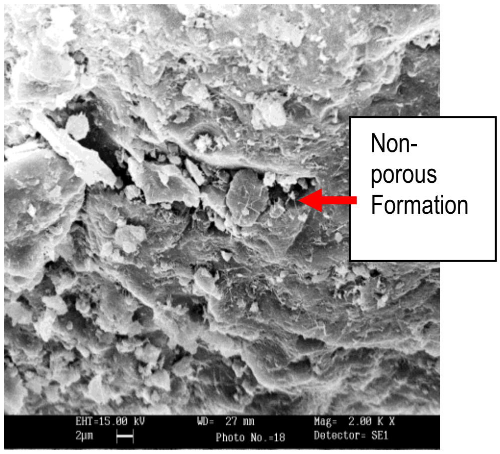


Figure 13: SEM of 55%FA+45%S

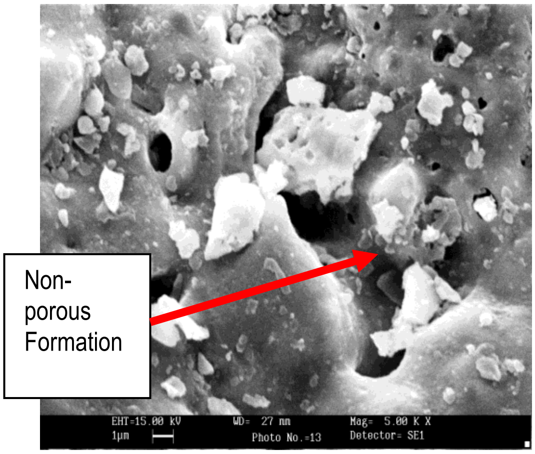


Figure 14 : SEM of 52%FA+40%S+8%C

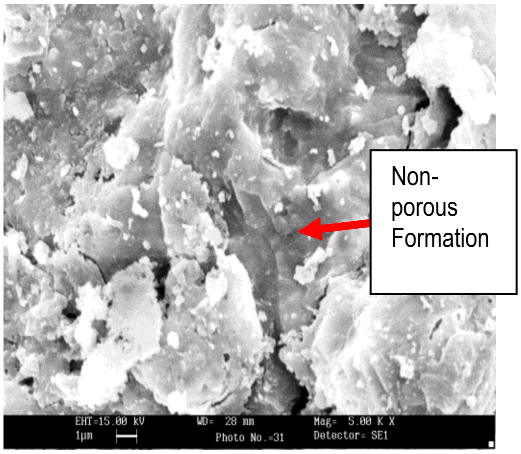


Figure 15 : SEM of 47%FA+45%S+8%C

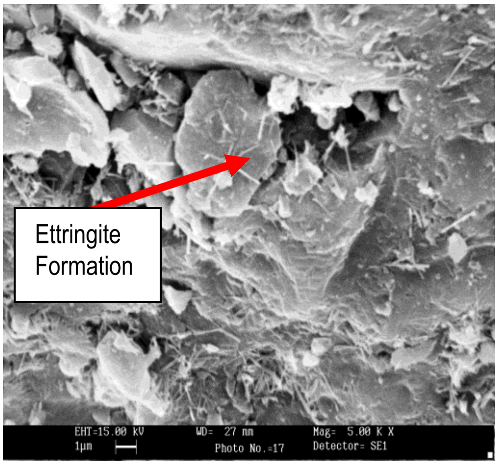


Figure 16 : SEM of 42%FA+50%S+8%C

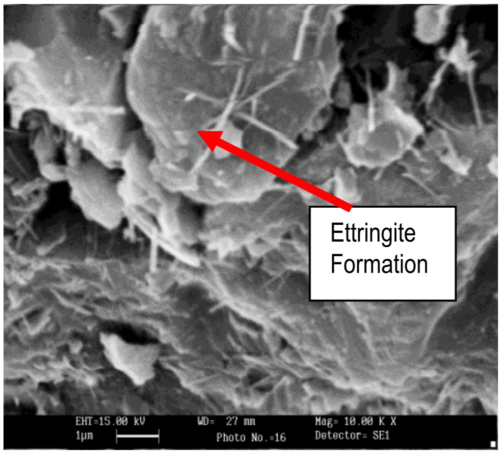


Figure 17 : SEM of 37%FA+ 55%S+8% C

4.5 Leaching Test

The data of TCLP test for different mixes are presented in Tables 12 and 13. Table 12 shows TCLP results including pH values of the mixes after 28 days of curing. It is observed that the pH of the leachate is between 6.9-10.9. Which is in the conformity to the values suggested by (US EPA, 1992, EEC, 1991 and DIN, 1984) for stabilization of heavy metals, higher pH conditions were preferred as most of the metal hydroxides have minimum solubility in pH range between 4-13. The reduction in leachability was related to combined effect of micro encapsulation and chemical fixation.

It has also been observed from Tables 12 that the limits of the heavy metals (Ni=1.65, Cr= 0.038, Zn=1.02, Cd=0.009, Cu=1.05 and Pb=0.095) present in the leachate of the mix

52%FA+8%C+40%S found to be less than the US EPA (1992) regulatory values (3, 5, 1, 5, 5 and 5 respectively), EEC (1991) regulatory values (2, 0.5, 10, 0.5, 5 and 5 respectively) and standards set by DIN (1984) as (2, 0.5, 10, 0.5, 10, 2 respectively) after 28 days of curing. On comparing the experimental results of leaching with US EPA (1992), European Economic Community EEC (1991) and DIN (1984), it is found that the heavy metals in the waste sludge have been completely stabilized by fly ash-cement system.

The average data of TCLP test were also presented in Table 13 for different mixes at various days of curing (28 to 365 days). From Table 13 it can be observed that the leaching of heavy metals in the mixes exhibiting decreasing trend with increase in curing period. Hence, the present stabilization process has great potential in retaining heavy metals and thereby, reducing the chances of contaminating ground water when used for geotechnical applications.

Table 12 : Results of Metal Leaching Test by TCLP method at 28 days of Curing

Composition of Mix	**Leachate pH**	**Concentration of Heavy Metal (ppm)**					
		Ni	**Cr**	**Zn**	**Cd**	**Cu**	**Pb**
62%FA+8%C+30%S	8.2	1.89	0.530	2.1	0.06	3.31	0.11
57%FA+8%C+35%S	7.7	1.73	0.080	1.35	0.04	1.26	0.38
52%FA+8%C+40%S	9.6	1.65	0.038	1.02	0.009	1.05	0.095
47%FA+8%C+45%S	10.9	0.24	0.09	0.81	0.05	0.98	0.27
42%FA+8%C+50%S	8.3	0.41	0.08	0.18	0.05	0.03	0.16
37%FA+8%C+55%S	7.1	1.34	0.210	0.64	0.002	0.06	0.21
32%FA+8%C+60%S	6.9	1.93	0.08	1.89	0.002	0.09	0.19
Thresholds[a]	4-13	0.4-2	0.1-0.5	2-10	0.1-0.5	2-10	0.4-2
Thresholds[b]	7-11	<3	<5	<5	<1	<5	<5
Thresholds[c]	4-13	0.4-2.0	0.1-0.5	2-10	0.1-0.5	2-10	0.4-2.0

[a]*Standards for the landfill of waste (EEC 1991)*
[b]*Standards for the landfill of waste (US EPA 1992)*
[c]*German standard procedure for water, wastewater and sediment testing (DIN 38414-S4 984)*

5.0 Conclusions

On the basis of the present study, the following conclusions were drawn:

- The compressive strength of mix 52%FA+8%C+40%S has been observed as 37, 39 and 45 MPa at 28, 90 and 365 days of curing respectively.

- The maximum compressive strength of mix 55%FA+45%S at 28, 90 and 365 days of curing were 18.5, 20 and 23 MPa respectively.

- As curing time increases, the compressive strength also increases, which shows that the mix is strong and durable. The significant increase in compressive strength is observed between 14 to 28 days of curing periods. However, on increasing the curing time up to 90 days, the mix not only maintains its strength but also the enhancement in strength continues.

- The pH values of the mixes were also found in the range of 6.9-10.9 at which the solubility of heavy metals is minimum.

- On analyzing the mix by atomic absorption spectrophotometer (AAS), it has been observed that the concentration of heavy metals in the leachate is drastically reduced. This process is so effective that it immobilizes 97 to 100% heavy metals in the leachate.

- It is also observed that the quantity of waste sludge could be added maximum up to 45% in the fly ash. The addition of waste sludge beyond 45% decreased the strength of the mix due to development of shrinkage cracks.

Table 13: Average Results of Metal Leaching Test by TCLP Method at Various Curing Periods of the Mixes (62%FA+8%C+30%S, 57%FA+8%C+35%S, 52%FA+8%C+40%S, 47%FA+8%C+45%S, 42%FA+8%C+50%S, 37%FA+8%C+55%S, 32%FA+8%C+60%S)

Metals	Concentration of Heavy Metals in the Waste Sludge (ppm)	Concentration of Heavy Metals in the Leachates (ppm) at Various days of Curing											
		28	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**365**
Nickel	98	1.31	1.02	1.50	0.94	0.81	0.63	0.58	0.31	0.08	0.07	0.066	0.07
Chromium	27	0.16	0.03	0.03	0.003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.003
Zinc	30	1.14	0.91	0.89	0.75	0.63	0.41	0.31	0.009	0.004	0.002	0.00	0.00
Cadmium	12	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	07	0.97	0.00	0.006	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead	4.5	0.20	0.09	0.095	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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