Unconfined Compressive Strength of Fly Ash Mixed With Lime Precipitated Waste Sludge and Cement

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Abstract— **For an effective disposal of fly ash, avoiding environmental pollution, it is necessary to utilize it on a continuous basis for some beneficial purposes. The present study investigated the feasibility and effectiveness of the fly ash along with lime precipitated waste sludge and cement. The Unconfined Compressive Strength (UCS) tests were carried out on the specimens comprising of fly ash (FA), (5 to 35%) lime precipitated electroplating waste sludge (S) and (2-20%) cement at 7 and 28 days of curing periods. The results of UCS tests indicated that the strength of fly ash increases substantially on addition of lime precipitated sludge and cement. It has been observed that compressive strengths of cement stabilized fly ash were smaller than the cement-sludge stabilized mix. It has also been observed that the strength was increasing upto 20% sludge addition to fly ash-cement mix, however, the strength started decreasing on further addition of sludge beyond 20% to the fly ash-cement combination. The most effective percentage of fly ash-cement-sludge was found as 72%FA+20%S+8%C. The UCS of this mix was found as 18 and 25 MPa at 7 and 28 days of curing respectively. This is substantially higher than the UCS of plain fly ash (1.0 and 2.5 MPa) at the same curing periods respectively. The X-ray analyses of some selected samples using EDX technique were also carried to study the elemental analyses of the various mixes. The EDX data showed that the experimental results obtain by UCS tests were in conformity with the chemical findings of EDX**

Keywords— **Fly ash, Waste Sludge, Cement, UCS, EDX**

I. INTRODUCTION

Fly ash produced from the thermal power plants as by-product requires large area for storage. Its disposal, without adversely affecting the environment, is a matter of global concern. Fly ash management has taken considerable strides over the past few years. Researchers [1-10] have attempted to convert this waste into useful construction materials by exploring viable avenues for effective fly ash management. The fly ash can be utilized in bulk in geotechnical engineering applications such as construction of highway, railway embankments, as a backfill material of retaining walls and also as a sub-base and base course of roads. An important engineering property that is necessary for using fly ash in many geotechnical applications is its strength, which depends mainly upon the compaction and densification of fly ash fill and unconfined compressive strength. 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 being utilized in cement, concrete, bricks, 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 Ni, Cr, Pb, Cu, Cd and Zn etc., [11]. As the restrictions on landfilling 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 [12-15]. The results of these interactions are the stable forms of waste which are non-hazardous or less hazardous than raw material [16-18]. Keeping in view the environmental acceptability of the mix containing fly ash, waste sludge and cement, the present investigation is carried out which serves two purposes viz., 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. The X-ray analyses of some selected samples using EDX technique were also carried to study the elemental analyses of the various specimens. The EDX data indicated that the results obtain by UCS is in conformity with the chemicals obtained by EDX analyses.

II. EXPERIMENTAL PROGRAMME

A brief description of the material used in this investigation along with the various tests conducted in the present study is as follows.

Test Material

In this study, the materials used are:

(i) Fly ash (FA)

(ii) Waste Sludge(S)

(iii) Cement(C)

(iv) Lime used as a precipitating agent

Fly ash

The fly ash used in the study was brought from National Thermal Power Station situated at Dadri (Ghaziabad) in Uttar Pradesh-India. Fly ash is classified as silt of low compressibility (ML). The physical and chemical properties of fly ash are shown in Tables–1 & 2.

Physical Properties

The physical properties of the fly ash used are shown in Table–1.

Table–1 Physical Properties of Fly ash

S. No.	Constituent/Property	Value
1.	Colour	Grey
2.	Percent passing 75 µ sieve	76%
3.	Size of the particle	0.001-0.30mm
4.	Maximum dry density (MDD)	1.183 g/cc
5.	Optimum moisture content (OMC)	26%
6.	Specific gravity	2.02 at 27^{o}C
7.	Surface area	3060 cm^2/g
8.	Plastic Limit	Non-plastic
9.	Unburnt carbon	11.80%
10	Classification	ML

Chemical Composition

The chemical compositions of Dadri fly ash are shown in Table–2. As per ASTM C 618-03[19] if fly ash containing silica more than 35% and the combined percentage of silica, alumina and iron oxide more than 70% and CaO is less than 10%. Accordingly, NTPC Dadri fly ash is classified as Class F fly ash.

Table–2 Chemical Properties of Fly ash

Constituent/Property	Value (%)
Al_2O_3	50.40
SiO_2	42.97
CaO	4.06
Fe_2O_3	1.17
MgO	0.60
Pb	0.50
Zn	0.30

Electroplating Waste Sludge

Electroplating waste sludge was collected from one of the electroplating industries in Aligarh City, India, in which Nickel, Chromium, is done, associated mostly of lock and other allied industries. 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. The physical properties and heavy metal concentration of electroplating sludge are shown in Tables–3 & 4 respectively.

Table–3 Physical Properties of Electroplating Waste

Constituent/Property	Value
Total solids	12835mg/l
Total dissolved solids	6417.2mg/l
Total suspended solids	121927mg/l
Specific gravity	1.022
pH	1.2

Table–4 Heavy Metal Concentration in Electroplating Waste Sludge

Metal	Concentration(mg/l or ppm)
Nickel	910
Chromium	113
Zinc	550
Cadmium	200
Lead	25

Cement

The cement used in this study was OPC JP-43 grade. The test on cement was conducted in accordance with IS: 269[20]. The physical properties of cement are given in Table–5.

Table–5 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

PREPARATION AND TESTING OF SPECIMENS

The lime precipitated electroplating waste sludge was dried, pulverized, sieved through 425µ IS sieve. Fly ash was dried in oven for 24 hours and sieved through 425µ IS sieve. The standard Proctor compaction test was carried out using the equipment and procedure as specified in [21] 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 10cm ×

10cm × 10cm cubes were casted for various percentages of fly ash (FA), electroplating waste sludge (S) and cement (C) as shown in Table–6. After 24 hours, the cubes were taken out from the moulds and cured for 7 and 28 days using temperature controlled curing tank. The cured cubes were tested for unconfined compressive strength determination by compression testing machine.

Table–6 Details of Various Test Conditions

Mix	Unconfined Compressive Strength (UCS) Test	EDX Test
Fly ash (FA)	7 and 28 days	7 and 28 days
95%FA+05%S	7 and 28 days	-
90%FA+10%S	7 and 28 days	-
85%FA+15%S	7 and 28 days	-
80%FA+20%S	7 and 28 days	-
75%FA+25%S	7 and 28 days	-
70%FA+30%S	7 and 28 days	-
65%FA+35%S	7 and 28 days	-
98%FA+02%C	7 and 28 days	-
96%FA+04%C	7 and 28 days	-
94%FA+06%C	7 and 28 days	-
92%FA+08%C	7 and 28 days	-
90%FA+10%C	7 and 28 days	-
88%FA+12%C	7 and 28 days	-
86%FA+14%C	7 and 28 days	-
84%FA+16%C	7 and 28 days	-
82%FA+18%C	7 and 28 days	-
80%FA+20%C	7 and 28 days	-
93-75%FA+2-20%C+05%S	7 and 28 days	7 and 28 days
88-70%FA+2-20%C+10%S	7 and 28 days	7 and 28 days
83-65%FA+2-20%C+15%S	7 and 28 days	7 and 28 days
78-60%FA+2-20%C+20%S	7 and 28 days	7 and 28 days
73-60%FA+2-20%C+25%S	7 and 28 days	7 and 28 days
68-60%FA+2-20%C+30%S	7 and 28 days	7 and 28 days
63-60%FA+2-20%C+35%S	7 and 28 days	28 days

III. RESULTS AND DISCUSSION

UCS of Plain Fly ash (FA)

The result of unconfined compressive strength (UCS) of fly ash (FA) is shown in Fig. 1. It can be observed that the UCS of FA is as low as 1.0 and 2.5 MPa at 7 and 28 days of curing. The result is in conformity with the chemical composition and classification of fly ash, which was classified as F type, and the CaO content in the present fly ash is very low which is primarily responsible for gaining strength in presence of water along with silica and alumina.

UCS of Plain Fly ash Mixed with Waste Sludge

The results of unconfined compressive strength tests of the mix containing varying percentages of electroplating waste sludge (from 5 to 35%) and fly ash at 7 and 28 days of curing are shown in Fig. 2. 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 with increased waste sludge percentage in fly ash. However, it may also be observed that the increase in the compressive strength is upto 20% 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. The maximum compressive strength of mix 80%FA+20%S at 7 and 28 days of curing were observed as 7, and 9 MPa respectively.

UCS of Plain Fly ash Mixed with Cement

Cement in varying percentages by weight of fly ash (2–20% with an increment of 2%) was added to the fly ash. The results are presented in Fig. 3 which, shows that on increasing the cement percentage, unconfined compressive strength of fly ash-cement mix is also increases, however, the significant increase in strength was observed from 8.2 MPa at 6% cement to 13 MPa at 8% cement at 7 days curing, while at 20% cement the compressive strength was observed as 20 MPa at7 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 correlations.

UCS of Plain Fly ash Mixed with Cement and Waste Sludge

The unconfined compressive strength tests of mix containing varying percentages of electroplating waste sludge (5 to 35%) and cement varying from 2% to 20% with a step of 2% were carried out, and the results are shown in Figs. 4 to 10. From Fig. 4 it has been observed that for 87%FA+8%C+5%S mix the values of compressive strength at 7 and 28 days of curing are 15 and 17.2 MPa respectively, which are almost equal to the compressive strength of 92%FA+8%C (15.1 and 18.4 MPa respectively). The similar results are found at other combination of FA+S mixes.

It has also been observed that the significant gain in strength exhibited for waste range 15 to 20%. The percent increase in 28 days unconfined compressive strength for mixes containing 77%FA+15%S+8%C is 900% and 72%FA+20%S+8%C is 1100%. However, on addition of waste sludge to fly ash beyond 20% the decrease in compressive strength can be observed for mix 67%FA+25%S+8%C. The UCS values of this mix are 15.3 and 19.2 MPa at 7 and 28 days of curing respectively. The decrement in the strength of the mix beyond 20% sludge is might be due to presence of sulphate, chloride and boric acid etc., present in the mix. Sulfate attack causes 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 [22-23]. The softening and disintegration is specifically due to the attack by magnesium sulfate as mentioned earlier and leads to strength loss and cracking.

Energy Dispersive X-ray Spectroscopy (EDX)

The X-ray analyses of some selected samples using EDX technique was carried out by JEOL jsm-6510w instrument equipped with an energy dispersive X-ray spectroscopy module (EDS) Oxford INCAX model. Metalized samples were prepared with carbon sputtering. EDX semi quantitative analyses were made at 20kv and a reference current of 300µA on powder samples. The EDX microanalyses have been carried out in spot mode over each different crystalline phase, at the limit detection of 0.2%. Specific surface area measurements were made with multi point BET technique using a Micromeritics ASAP 2010 analyzer. Specific area values were calculated from the isotherm data using Brunauer-Emmett-Teller (BET) equation in a relative pressure range of 0.003-0.3.

The percentage of the elements analyzed is given in Table-7 and Figs. 11 to 27.

The EDX of plain fly ash shows (Table-7) that oxides of alumina and silica are more than the oxides of calcium present in the fly ash. The deficiency of CaO in fly ash resulted lower strength in presence of water. However, the study also suggests that the plain fly ah contains some heavy metals such as lead, zinc and iron which is environmentally undesirable.

The EDX of waste sludge indicted that it contains only $CaCO_3$ and some heavy metals in it. The presence of excess $CaCO_3$ might be due to the use of lime for precipitation of waste sludge.

The EDX of cement shows the amount of various chemicals such CaO, Al_2O_3 and SiO_2 primarily present in the cement. The percentages of these elements are confirming the provisions of relevant IS codes.

The EDX analyses of mixes 87%FA+5%S+8%C, 82%FA+10%S+8%C, 77%FA+15%S+8%C and 72%FA+20%S+8%C at 7 and 28 days of curing indicated (Figs. 15 to 22) that on increasing the lime treated waste sludge in fly ash and cement the amount of CaO, Al_2O_3 and SiO_2 were also increasing which are chiefly responsible for the pozzolanic reactions results in gain in strength of the mix. These findings of the test results obtained by UCS have been clearly verified by EDX analyses of these mixes.

The Figs. 23 to 27 and Table-7 shows the results of EDX analyses of mixes 67%FA+25%S+8%C, 62%FA+30%S+8%C at 7 and 28 and 57%FA+35%S+8%C at 28 days of curing respectively. It has been observed from the results that on further addition of waste sludge beyond 20% in fly ash and cement the amount of $CaCO_3$ is increasing where as the oxides of calcium, silica and alumina are decreasing. The presence of excess amount of calcium carbonate enhances carbonation which results in the loss in strength of the mix. These finding are in conformity with the UCS test results as shown in Figs. 8 to 10.

IV. CONCLUSIONS

A series of UCS tests were performed to study the effects of waste sludge, cement, and curing periods on the strength of fly ash. The following are the conclusions drawn from the present investigations.

It has clearly been observed from the present investigation that Dadri fly ash which is of class F type can not be used without stabilizing it. The UCS of plain fly ash was obtained as low as 1.0 and 2.5 MPa at 7 and 28 days of curing respectively.

The unconfined compressive strength (UCS) of mix 72%FA+20%S+8%C has been observed as 23 and 30 MPa at 7 and 28 days of curing periods respectively.

The gain in strength of the mix 72%FA+20%S+8%C has been observed as 1100% as compared to plain fly ash at 28 days of curing.

It has also been observed that the waste sludge should not be added more than 20% in the fly ash. The UCS results show that the strength of the mix beyond 20% waste sludge started decreasing. The strength of the mix 67%FA+25%S+8%C at 7 and 28 days of curing was obtained as 15.3 and 19.2 MPa which is 35 and 37% lesser than the strength of 72%FA+20%S+8%C mix at the same curing periods respectively.

As curing time increases, the compressive strength also increases, which shows that the mix is becoming strong and durable. The significant increase in compressive strength is observed at 28 days of curing periods. The increment in the strength of mixes with curing period signifies that the mixes are becoming durable, which enables the stabilization of heavy metals with passage of time.

The EDX analyses confirm the findings of the UCS tests conducted on various combinations of mixes.

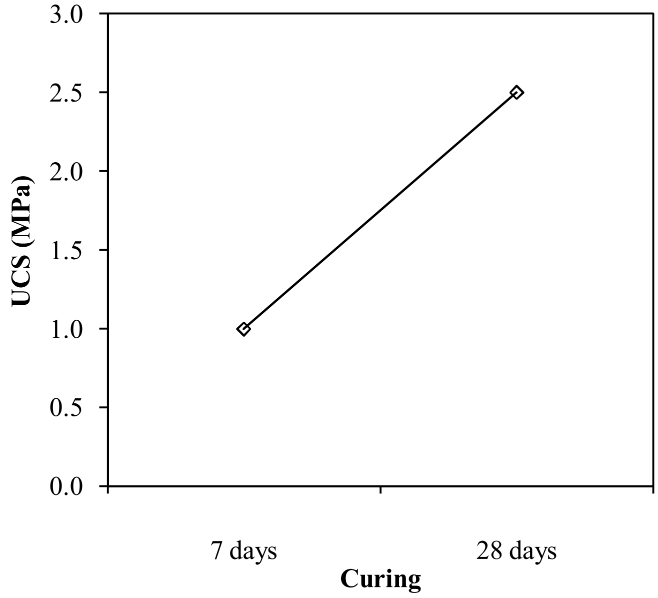

Fig. 1 Unconfined Compressive Strength (UCS) of Fly ash

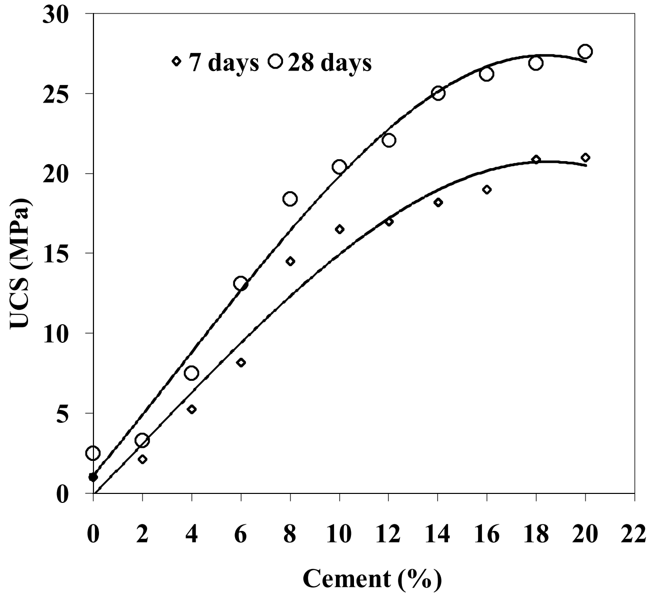

Fig. 3 Variations in UCS of Fly ash with Cement and Curing

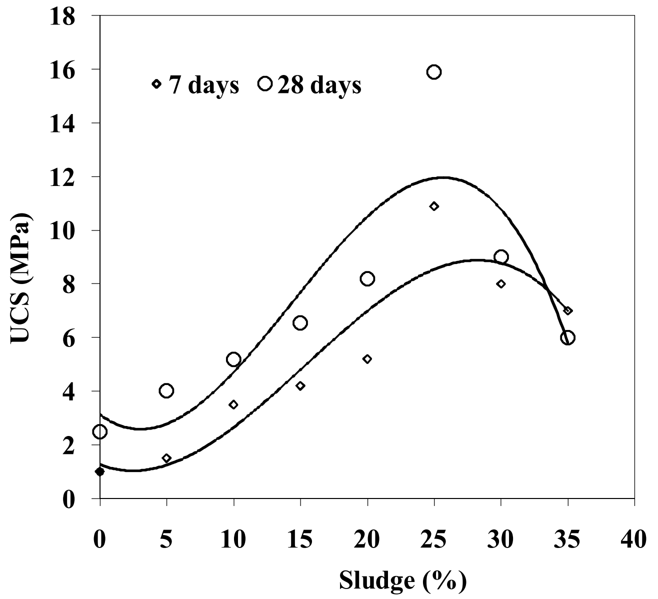

Fig. 2 Variations in UCS of Fly ash with Sludge and Curing

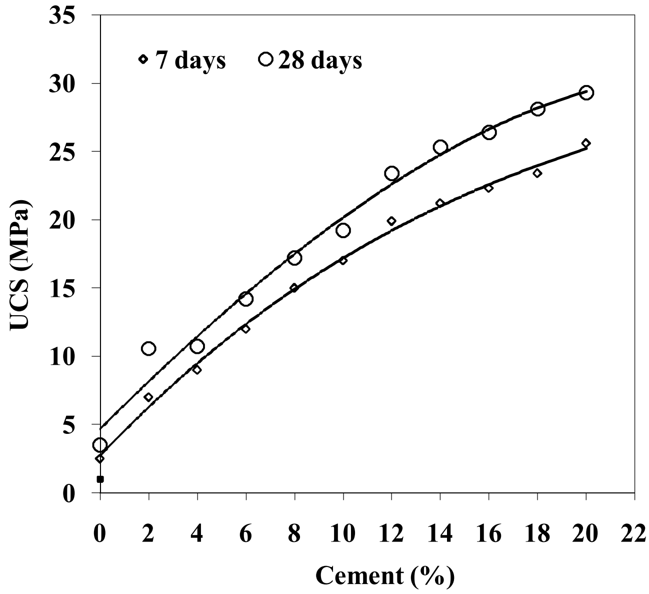

Fig. 4 Variations in UCS of FA+C+5%S

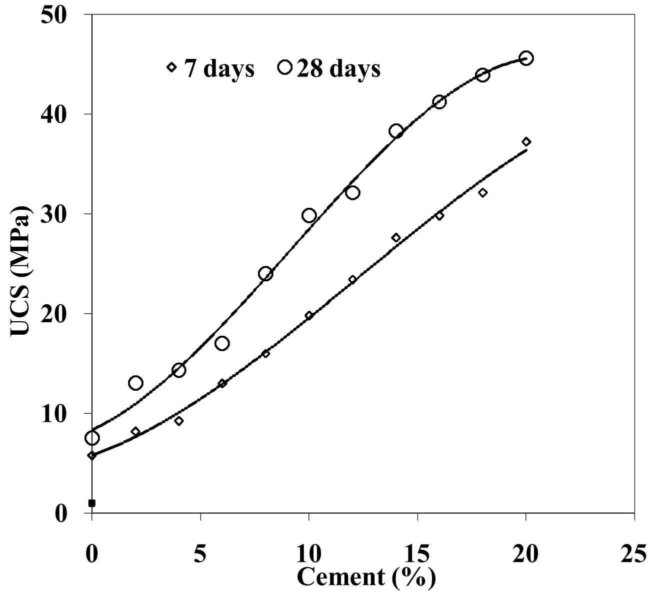

Fig. 5 Variations in UCS of FA+C+10%S

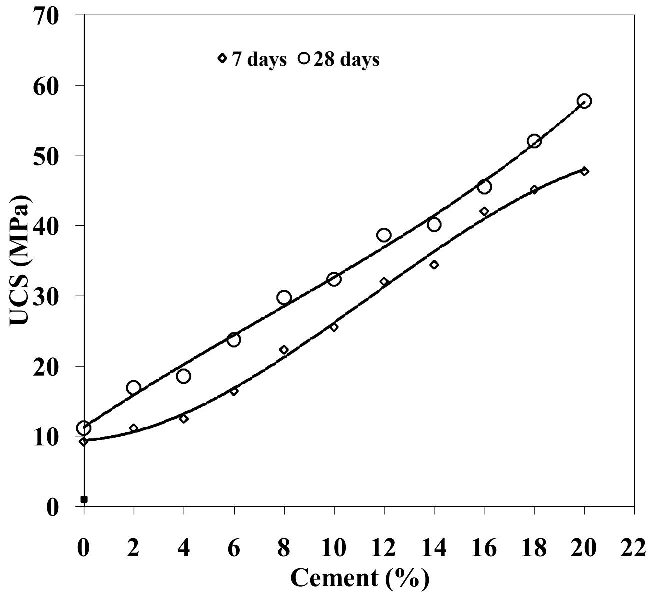

Fig. 7 Variations in UCS of FA+C+20%S

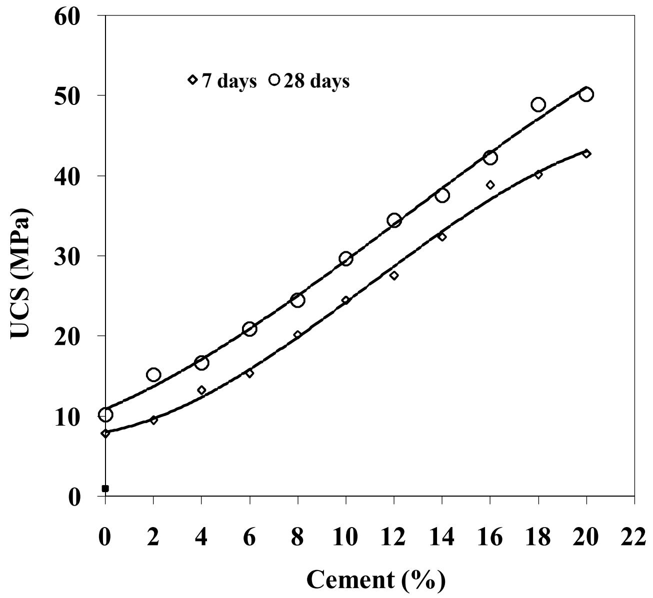

Fig. 6 Variations in UCS of FA+C+15%S

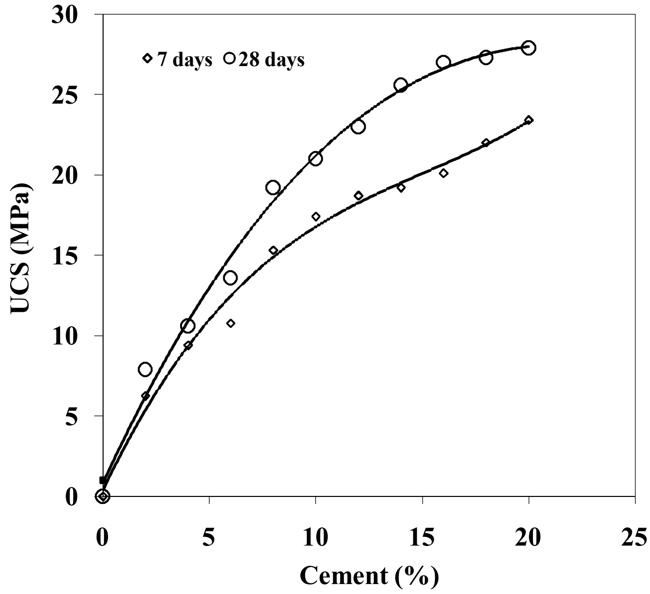

Fig. 8 Variations in UCS of FA+C+25%S

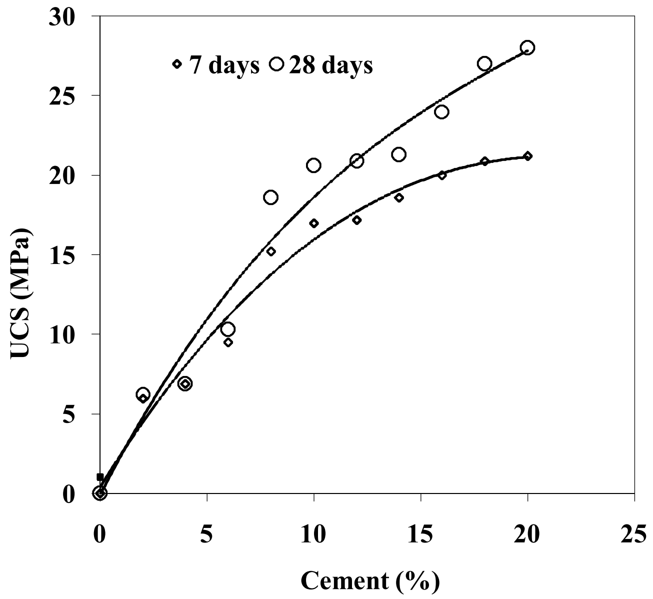

Fig. 9 Variations in UCS of FA+C+30%S

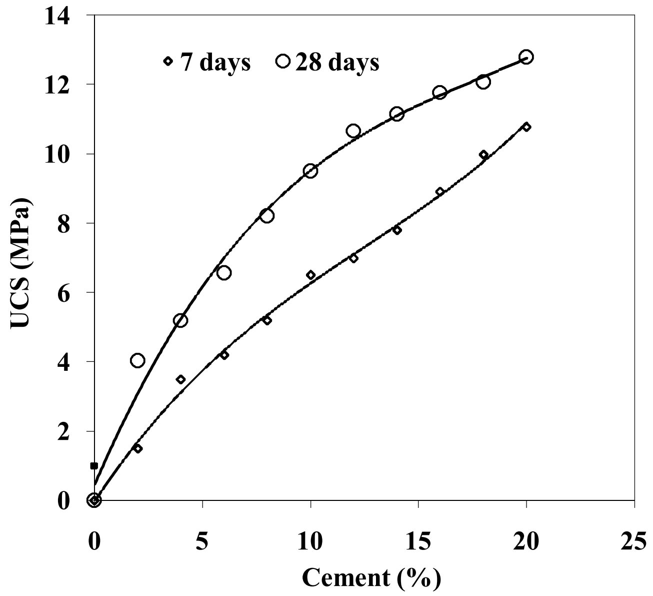

Fig. 10 Variations in UCS of FA+C+35%S

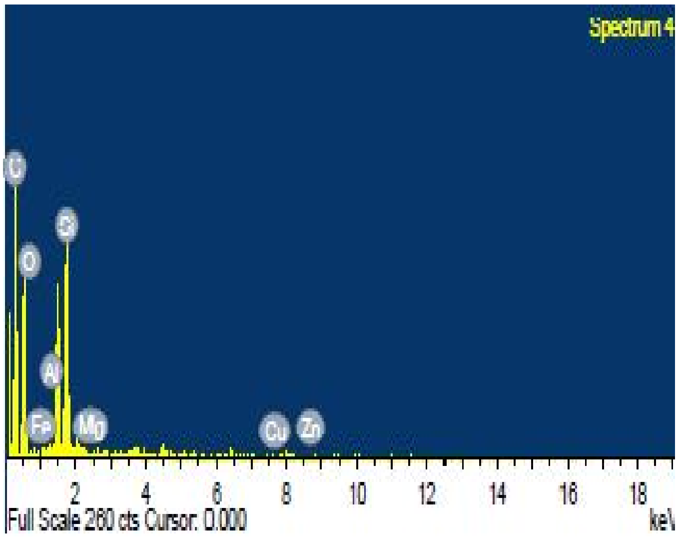

Fig. 11 Energy Dispersive X-ray (EDX) of Fly ash (7 days)

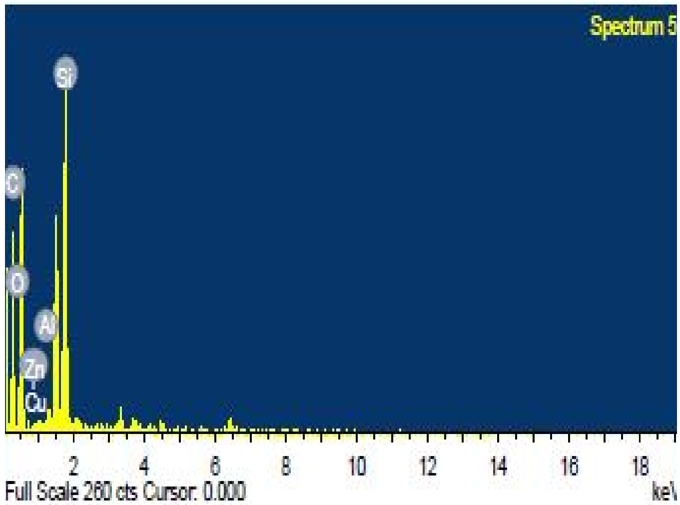

Fig. 12 Energy Dispersive X-ray (EDX) of Fly ash (28 days)

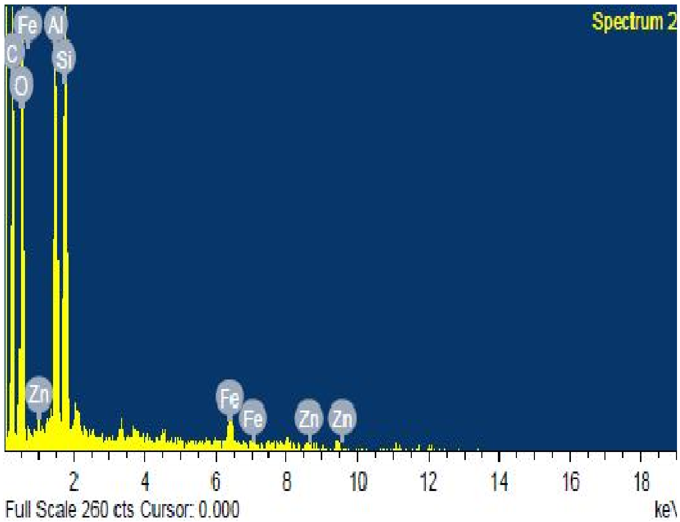

Fig. 13 Energy Dispersive X-ray (EDX) of Cement

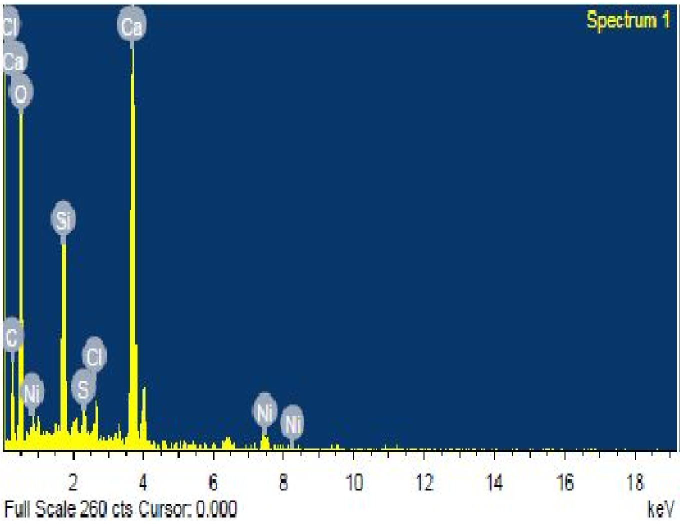

Fig. 14 Energy Dispersive X-ray (EDX) of Waste Sludge

Fig. 15 Energy Dispersive X-ray (EDX) of 87%FA+5%S+8%C (7 days)

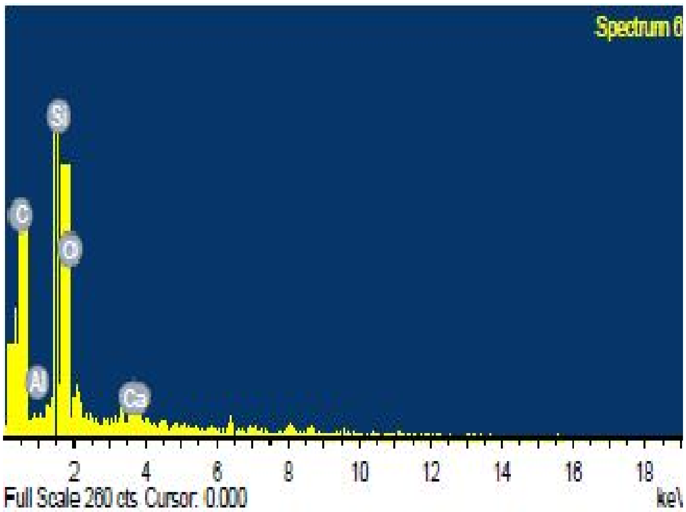

Fig. 16 Energy Dispersive X-ray (EDX) of 87%FA+5%S+8%C (28 days)

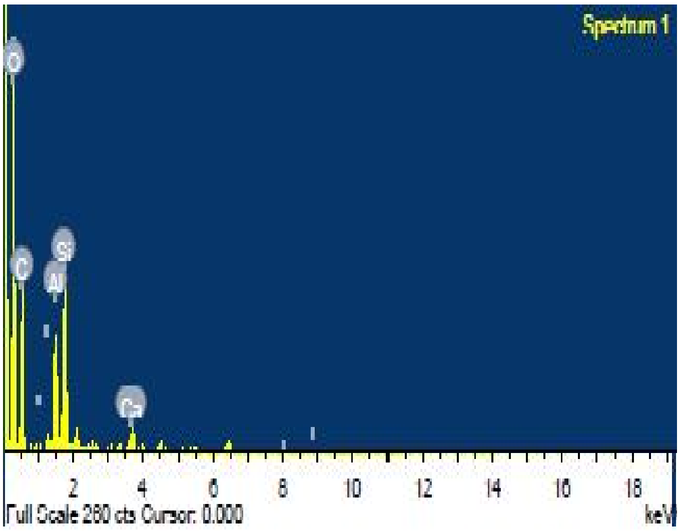

Fig. 17 Energy Dispersive X-ray (EDX) of 82%FA+10%S+8%C (7 days)

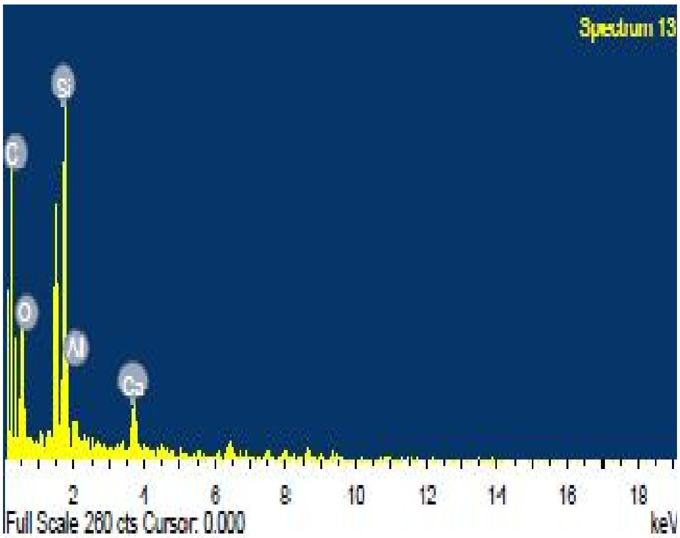

Fig. 18 Energy Dispersive X-ray (EDX) of 82%FA+10%S+8%C (28 days)

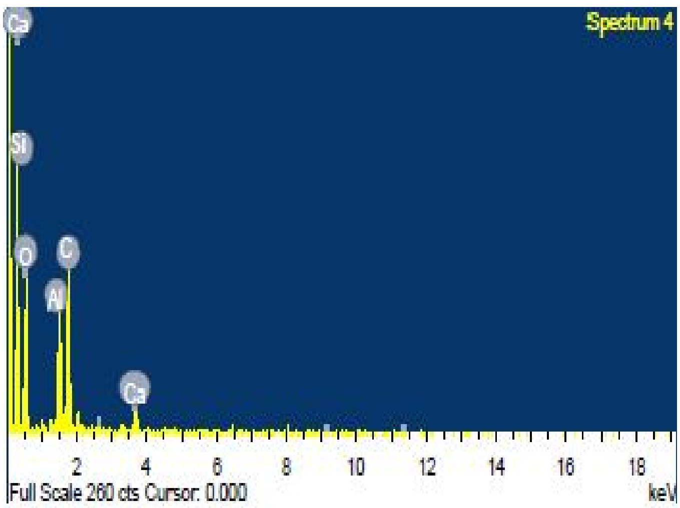

Fig. 19 Energy Dispersive X-ray (EDX) of 77%FA+15%S+8%C (7days)

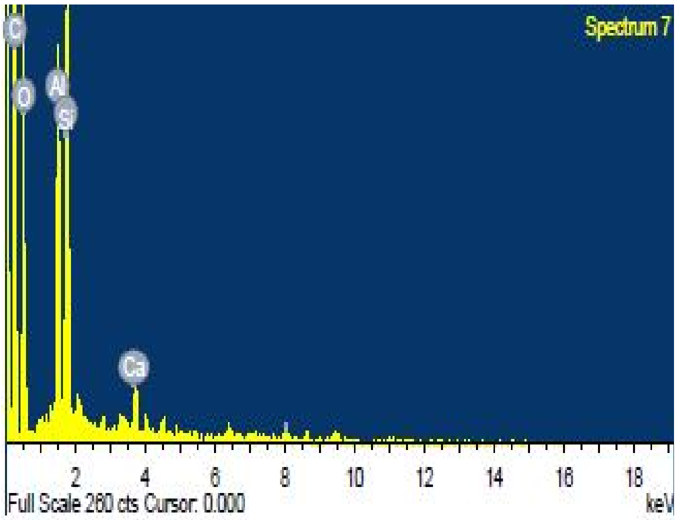

Fig. 20 Energy Dispersive X-ray (EDX) of 77%FA+15%S+8%C (28 days)

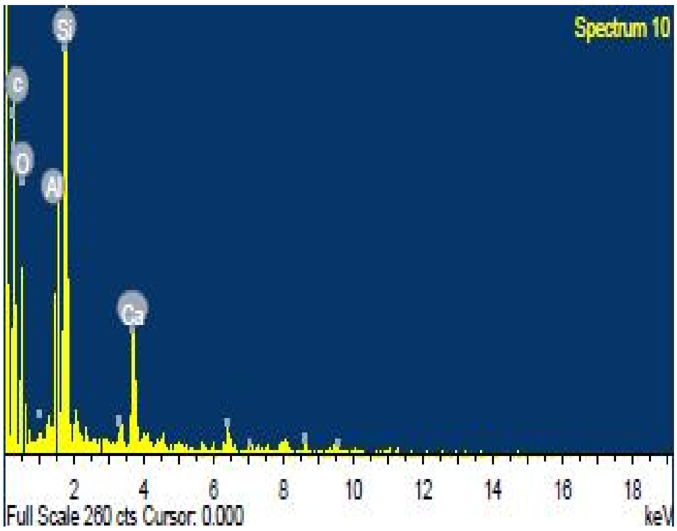

Fig. 21 Energy Dispersive X-ray (EDX) of 72%FA+20%S+8%C (7 days)

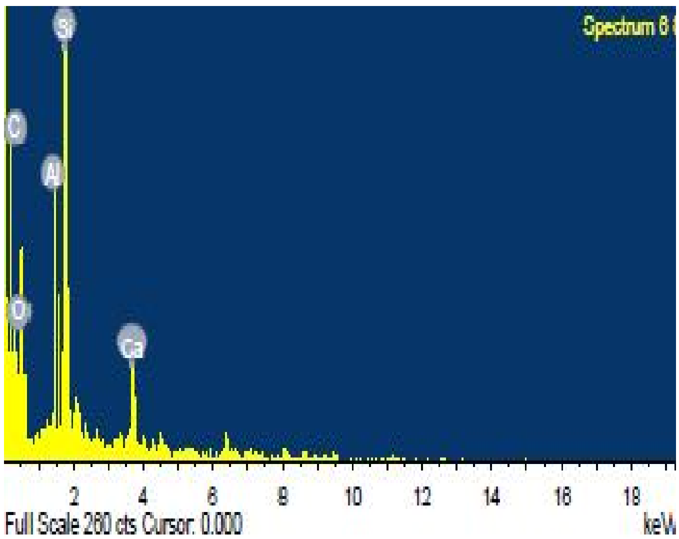

Fig. 22 Energy Dispersive X-ray (EDX) of 72%FA+20%S+8%C (28 days)

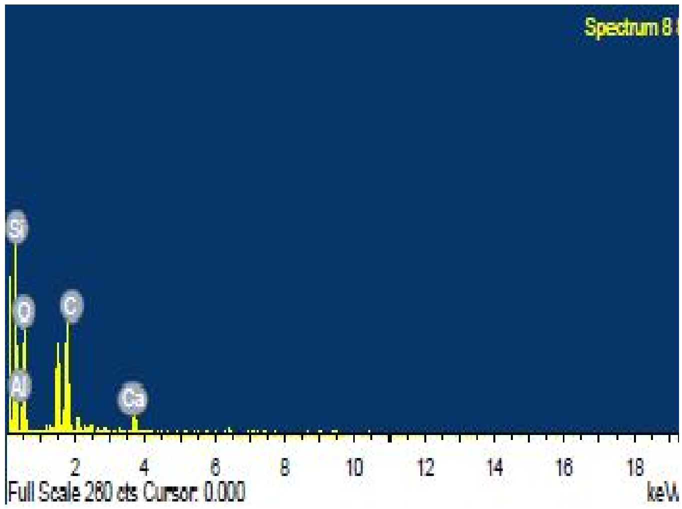

Fig. 23 Energy Dispersive X-ray (EDX) of 67%FA+25%S+8%C (7 days)

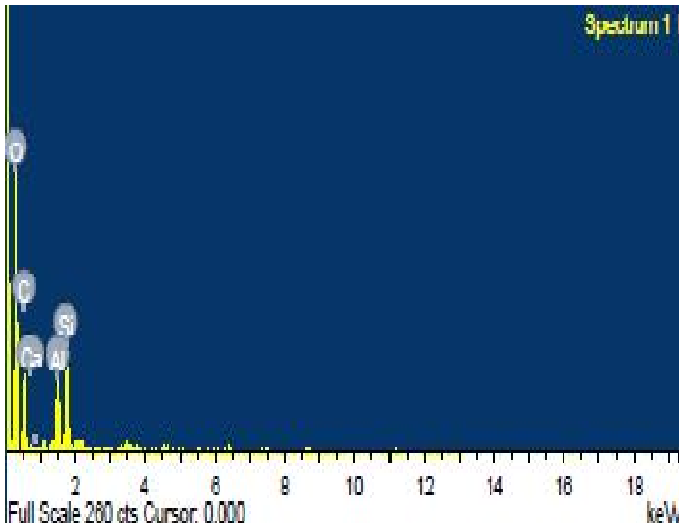

Fig. 24 Energy Dispersive X-ray (EDX) of 67%FA+25%S+8%C (28 days)

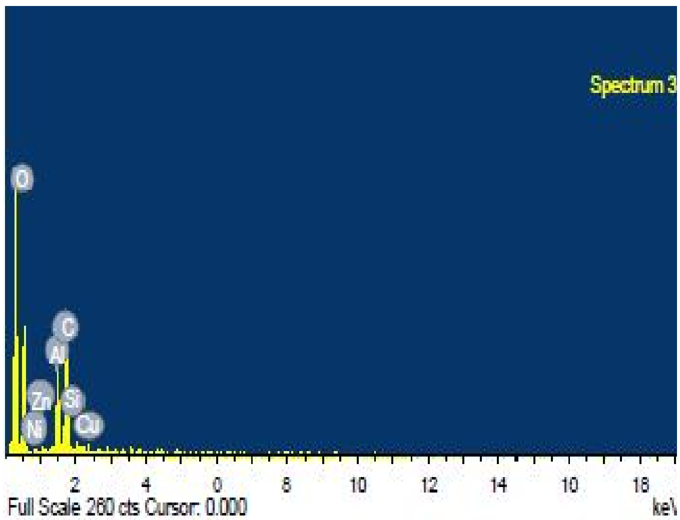

Fig. 25 Energy Dispersive X-ray (EDX) of 62%FA+30%S+8%C (7 days)

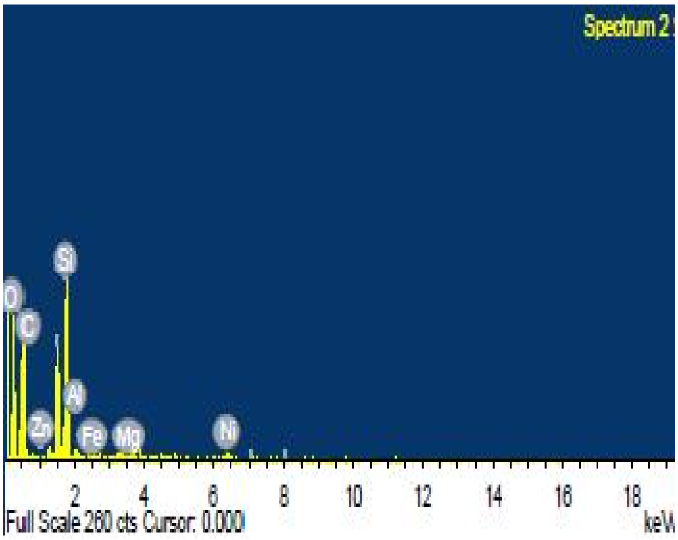

Fig. 26 Energy Dispersive X-ray (EDX) of 62%FA+30%S+8%C (28 days)

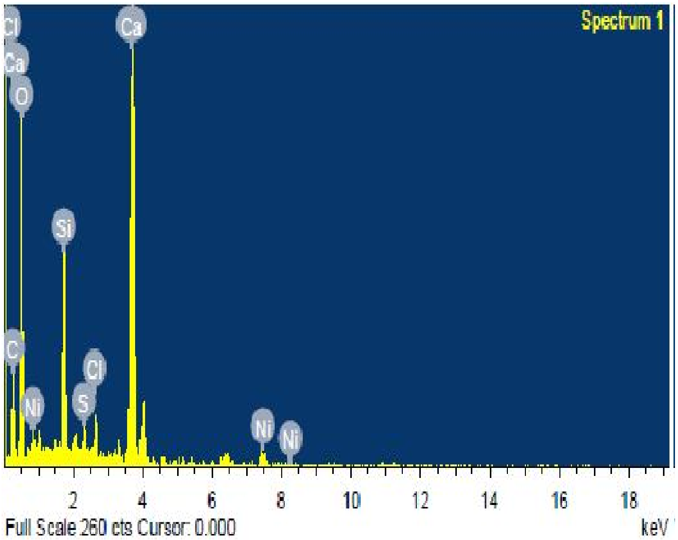

Fig. 27 Energy Dispersive X-ray (EDX) of 57%FA+35%S+8%C (28 days)

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Table–7 Data of Energy Dispersive X-ray (EDX)

Mix	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Pb (%)	Ni (%)	Zn (%)	$CaCO_3$ (%)	MgO (%)	Fe (%)	$CaSiO_3$ (%)
Fly ash (7 days)	4.00	42.97	50.0	0.50	-	0.40	4.00	-	1.17	-
Fly ash (28 days)	7.62	49.80	46.7	-	-	0.40	-	-	1.17	-
Lime Precipitated Waste Sludge (dry)	5.01	20.88	-	1.10	1.76	-	68.26	-	1.69	-
Cement	65.13	18.87	7.00	-	-	-	-	1.00	-	5.00
87%FA+5%S+8%C (7 days)	14.39	37.74	40.63	-	0.28	0.20	0.50	-	-	-
87%FA+5%S+8%C(28 days)	19.39	47.74	20.63	-	-	0.12	5.26	0.15	0.17	-
82%FA+10%S+8%C(7 days)	21.55	45.09	30.61	-	-	-	-	-	-	1.40
82%FA+10%S+8%C(28 days)	25.72	52.96	20.85	-	-	-	-	-	-	2.47
77%FA+15%S+8%C(7 days)	37.22	40.16	26.93	-	-	-	-	-	-	3.19
77%FA+15%S+8%C(28 days)	55.57	12.6	32.09	-	-	-	-	-	-	3.19
72%FA+20%S+8%C(7 days)	32.25	35.50	27.42	-	-	-	4.03	-	-	2.83
72%FA+20%S+8%C(28 days)	40.33	30.34	25.10	-	-	-	2.67	-	-	2.23
67%FA+25%S+8%C(7 days)	16.96	23.46	17.28	-	-	-	40.7	-	-	2.30
67%FA+25%S+8%C(28 days)	18.26	25.09	17.50	-	-	-	35.2	-	-	1.15
62%FA+30%S+8%C(7 days)	12.3	20.46	13.44	-	-	-	50.2	-	-	1.83
62%FA+30%S+8%C(28 days)	15.0	21.80	14.23	-	-	-	47.0	-	-	0.89
57%FA+35%S+8%C(7 days)	10.0	12.09	13.31	-	-	-	60.9	-	-	0.18
57%FA+35%S+8%C(28 days)	8.9	8.72	4.06	-	-	-	77.3	-	-	0.41