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Effect of Two Sources of Waste Fly Ash on Compressive Strength of Cementitious Mixtures

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ABSTRACT

This research was undertaken to study the effect of sulphate activation of Run of Station Ash (ROSA) blend with Red-Gypsum (RG), Plaster Board Gypsum (PG) and By-Pass Dust (BPD). Tests were prepared using binary and ternary steps. All mixes had similar water to binder (w/b) ratio of 0.3% and the water content was reduced in last mixes to obtain more compressive strength. Results showed PG and RG can be used as sulphate to form a sulphate activated pozzolan BPD-ROSA binder which could be used for low strength construction materials. The source of by-product material, BPD and ROSA, affected the material characteristics and mixtures.

INTRODUCTION

Industrial advancement increasing the production of waste materials has environmental implications. Recycling waste products of industries has been the subject of many researches all around the world. Various waste alternatives such as slags, fly ashes, borogypsum, phosphogypsum and other by-products have been used as additives in cement and concrete productions.

According to ASTM 618, if the content of pozzolan oxides (SiO_2+Al_2O_3+Fe_2O_3) is more than 70% the material satisfies the chemical requirements for use as a pozzolan. Fly ash is one of those materials. Because the pozzolanic reaction affects the strengths of materials, strength is used as an indication of pozzolanic reactivity.

Research on Fly ash, Lime and Phospho gypsum (FaL-G) reported that when gypsum was added to Fa-L mix, the compressive strength increased by 3 and 22 times in comparison with that of Fa alone and Fa-L at 28 days curing time, respectively [A.Ghosh and Ch. Subbarao, 2001]. FaL-G is a hydraulic binder that was used for bricks and hollow blocks [Kumar, 2002].

Sadeghi Pouya et al. [2007] investigated the optimised compressive strength of Basic Oxygen Slag - Bypass dust - Plaster board Gypsum. Plaster board gypsum can be used as a sulphate activator of slag.

This paper is the outcome of a PhD research project carried out at the Coventry University, UK, between 2005 and 2008 [Karami, 2009]. The objective of this paper is to evaluate and compare the effects of two different run of station ash on compressive strength of BPD- Gypsum binders. The intention is to see if this combination of waste materials can lead to an increase in the compressive strength of mixes for applications in construction products.

RAW MATERIALS

The raw materials used for this work included:

Ground waste plasterboard gypsum (PG) from plasterboard recycling plant (Lafarge Plasterboard Ltd) which passed sieve 600µm.

Run of Station Ash (ROSA) that is a by product from Ratcliff Power Station,UK; another kind of ROSA was obtained from Rugeley power station, UK.

Red Gypsum (RG) from Huntsman Tioxide, UK that was dried, ground and passed sieve 600µmm.

By-pass dust (BPD): Several kinds of BPDs were used in this project which varied in both physical and chemical characteristics.

The chemical composition of the materials is presented in Table 1.

Table1. Chemical Oxides Composition of the Starting Materials Used (in weight %)

Sample	ROSA				PG	BPD		RG
	Rugeley Ash (I)	Rugeley Ash (II)	Ratcliff Ash (I)	Ratcliff Ash (II)		BPD_1	BPD_2	
SiO_2	33.30	39.32	46.38	47.16	2.43	21.86	6.92	12.71
TiO_2	0.82	1.02	1.05	1.04	0.03	0.29	0.15	0.39
Al_2O_3	14.60	19.81	25.25	24.33	0.81	3.85	2.73	1.72
Fe_2O_3	16.89	9.25	8.33	8.86	0.36	2.57	0.80	21.26
MnO	0.16	0.10	0.18	0.16	0.00	0.02	0.01	2.66
MgO	8.32	4.52	2.42	2.22	0.40	1.13	0.77	6.18
CaO	19.62	12.58	5.27	4.71	37.30	53.40	36.79	35.89
Na_2O	0.29	0.36	0.88	0.70	0.03	0.41	1.22	0.00
K2O	1.01	1.19	2.08	2.14	0.24	3.64	15.04	0.02
$P2O_5$	0.27	0.82	0.64	0.53	0.02	0.08	0.06	1.62
SO_3	1.32	1.01	0.70	0.50	53.07	7.10	8.25	0.31
Total	100.18	99.61	99.53	99.56	94.69	94.35	94.22	89.86

EXPERIMENTAL PLAN

Mixtures were prepared in binary (Step1) and ternary (step2) combinations of ROSA, BPD, PG and RG, using 0.3 water to binder (w/b) ratio. Pastes were cast in 50 mm cubes samples and were fully compacted in three layers using a vibration table. After casting, moulds were kept in laboratory environment for 24 h. At this age, most specimens were demoulded and cured at 20 ± 1°C and 98% relative humidity until 3, 7 and 28 days. The result of compressive strength was calculated as the average of three specimens.

A large number of cementitious specimens using by-product materials in introduced in table 1were made in step 1 and step 2 with different proportions of each material.

RESULTS AND DISCUSSIONS

Step 1 Binary Combinations

The effect of material content of ROSA (Ratcliff Ash (I)), PG, RG and BPD(I) on increasing the compressive strength of the cementitious mixes was studied in step 1.

Figures 1 to 5 show the compressive strength of different combinations of the above by-product materials in different ages.

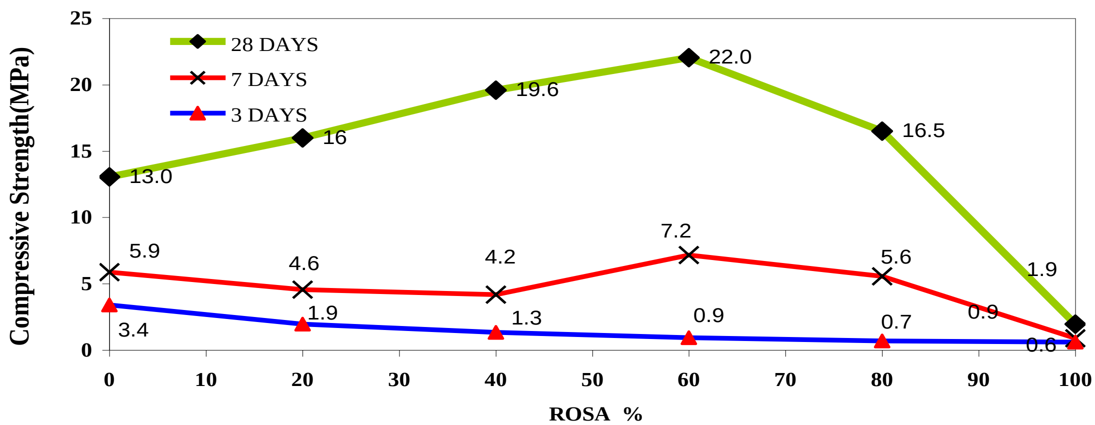

Fig. 1. Compressive Strength of ROSA-BPD Pastes at 3, 7, and 28 Days

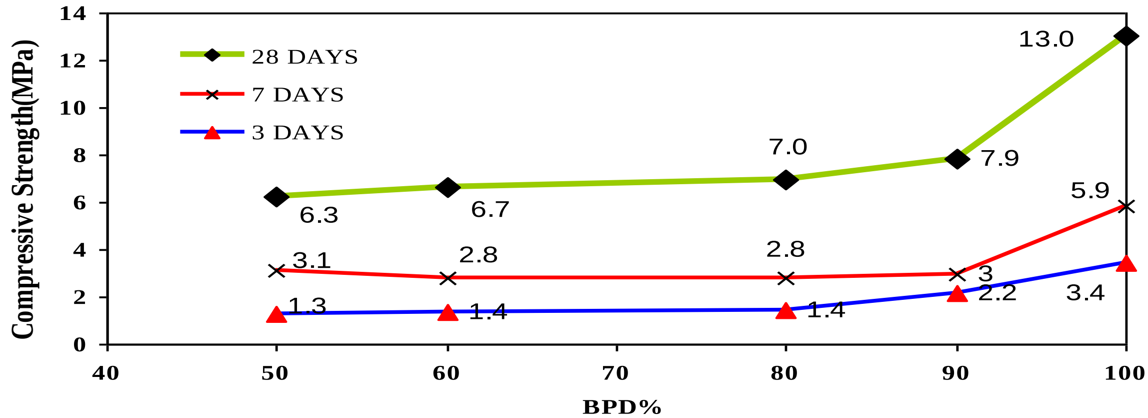

Fig. 2. Compressive Strength of RG-BPD Pastes at 3, 7, and 28 Days

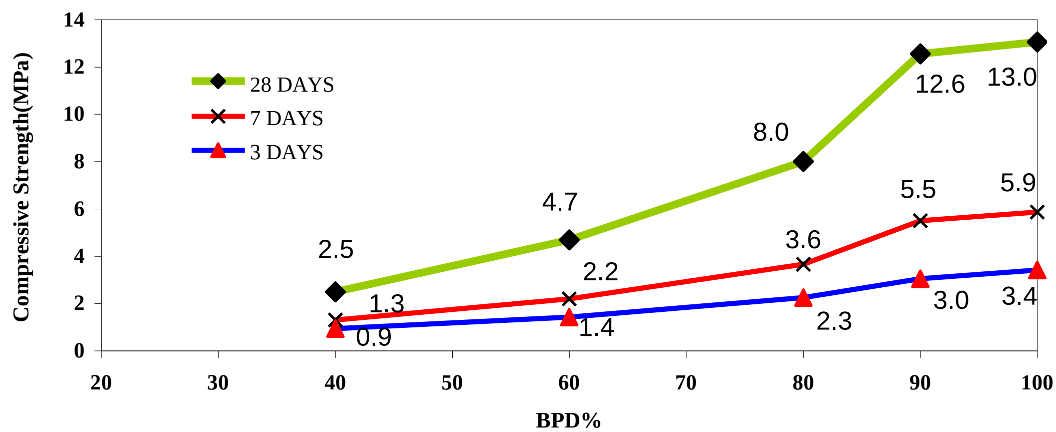

Fig. 3. Compressive Strength of PG-BPD Pastes at 3, 7, and 28 Days

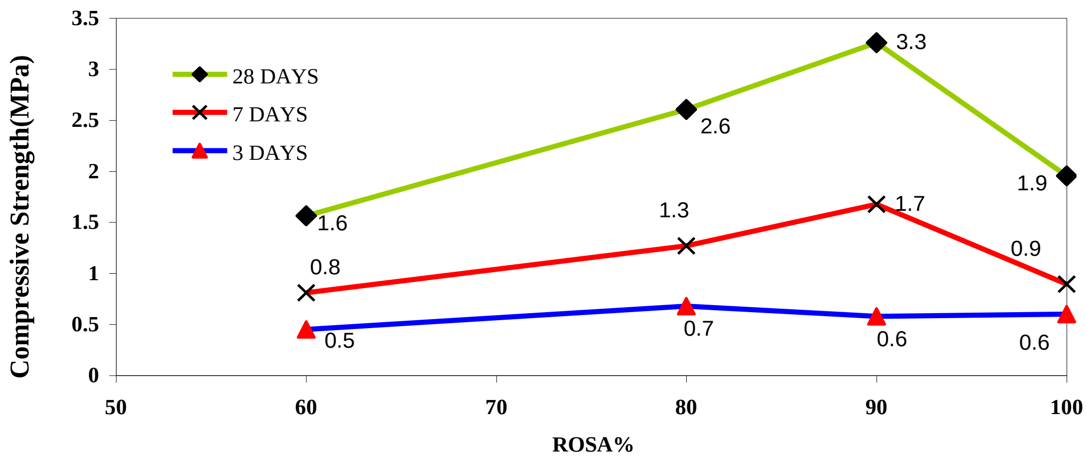

Fig. 4. Compressive Strength of ROSA-RG Pastes at 3, 7, and 28 Days

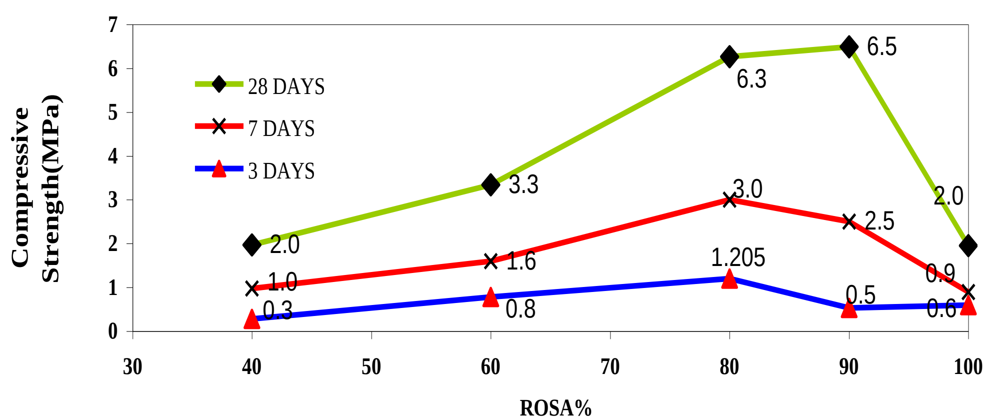

Fig. 5. Compressive Strength of ROSA-PG Pastes at 3, 7, and 28 Days

Figure 1 demonstrates the effect of ROSA on the compressive strength of the ROSA-BPD pastes. The compressive strength of mixes increased from the mix with 0% ROSA - 100% BPD with the mixture of 60% ROSA - 40% BPD. The highest compressive strength was for the mix 60% ROSA - 40% BPD then it decreased to the mix with 100% of ROSA. The high compressive strength of this mix at 7 days (7.17 MPa) might be attributed to the influence of rapid hydration at early age on microstructure of the ROSA-BPD paste.

In all mixes the compressive strength increased with curing time. The flow of mixes decreased by increasing the amount of ROSA because it absorbed water immediately after it was added to the binder. However, it released water later to the paste and the flow increased.

Using 40% of BPD was not a feasible quantity for use because BPD did not have similar chemical characteristics in different batches even if it was collected from the same source. However, increasing ROSA caused more compressive strength from 60% to 80%.

Figures 2 and 3 demonstrate the effect of BPD content on the compressive strength of the BPD-RG and BPD-PG mixtures. The compressive strength of mixes increased from 50% BPD to 100% BPD. The highest compressive strength was for the 100% BPD paste. In all mixes, the compressive strength increased with time. The flow of the mixes increased when BPD content increased.

Figures 4 and 5 demonstrate the effect of ROSA content on the compressive strength of the ROSA-RG and ROSA-PG. Because RG had a low compressive strength at high content and caused very sticky and dry paste, using RG was limited to 40% with ROSA. The highest compressive strength was for mix 90% ROSA - 10% RG. In all mixes the amount of compressive strength increased with time. The flow of pastes decreased when ROSA content was increased. The compressive strength of mixes increased from 60% ROSA to 90% of ROSA and the highest compressive strength was for the mix 90% ROSA - 10% PG (similar to RG mixes). In all pastes, the amount of compressive strength increased with time. The flow of pastes decreased when ROSA content increased.

PG and RG showed pozzolanic reaction with ROSA. PG had more effect on increasing compressive strength than RG with ROSA. It was because of the higher quantity of sulphate and carbon oxide in PG than RG. PG and RG had the role of Sulphate activators for BPD and ROSA. The reaction between gypsum and fly ash is based on the ability of sulphate ions to catalyse the alumina in fly ash.

Step 2 Ternary Mixes

In this step, a series of mixes were selected for BPD-ROSA combined with RG and PG. From the conclusions of previous research on strength optimisation of compressive strength of basic oxygen slag and plasterboard gypsum waste [Sadeghi Pouya et al. 2007], the compressive strength of ternary mixes did not change in a linear function. Results of this step and detail of mixes are shown in Tables 2 and 3.

Table 2. Characterisation of ROSA, BPD, and PG Mixes

Materials			Compressive Strength MPa.			Flow mm
ROSA%	BPD%	PG%	3 days	7 days	28 days	
85.5	5	9.5	0.81	2.5	14	No Flow
85	10	5	0.65	2.5	14.3	No Flow
81	10	9	0.63	2.3	15.8	No Flow
76.5	15	8.5	0.80	2.1	18	No Flow
76	19	5	0.5	2.1	17	No Flow
75	5	20	0.59	2.44	9.8	No Flow
72	18	10	0.68	2.3	16.3	No Flow
70	10	20	0.66	2.4	16	No Flow
68	17	15	0.89	1.79	15.4	No Flow
65	15	20	0.61	2	10.1	No Flow
60	20	20	1.12	2.3	5.4	No Flow

Table 3. Characterisation of ROSA, BPD, and RG Mixes

Materials			Compressive Strength (MPa)			Flow (mm)
ROSA%	BPD%	RG%	3 days	7 days	28 days	
85.5	5	9.5	1.16	3.5	7	No Flow
85	10	5	0.67	2.8	12.2	No Flow
81	10	9	1	4.3	8	No Flow
76.5	15	8.5	0.96	3.3	10	No Flow
76	19	5	0.64	3.8	8.2	No Flow
75	5	20	0.55	2	8.9	No Flow
72	18	10	1	2.9	13.5	No Flow
70	10	20	0.67	2.5	11	No Flow
68	17	15	0.82	4.5	12	No Flow
65	15	20	0.81	3.5	9.2	No Flow
60	20	20	1.03	2.12	4.9	No Flow

In ternary mixes, the results showed that in BPD-ROSA the use of PG or RG caused more compressive strength in every age due to their sulphate activation properties for both ROSA and BPD.

Figures 6 and 7 show the contour graph of the compressive strength of BPD-ROSA-RG and BPD-ROSA-PG mixes with different combinations after 28 days. One of the mixes is shown as an example in Figure 6 which indicates how the compressive strength of mixes could be found from the contours. The axels show ROSA and BPD contents and the rest of the combination is RG or PG which is not shown as an axel. The compressive strength of the mixes that were not made could be found from these contours. However, the actual compressive strength of the mix may be different to this interpolated strength from the contours because the interpolation of the results was done whit a limited number of the results.

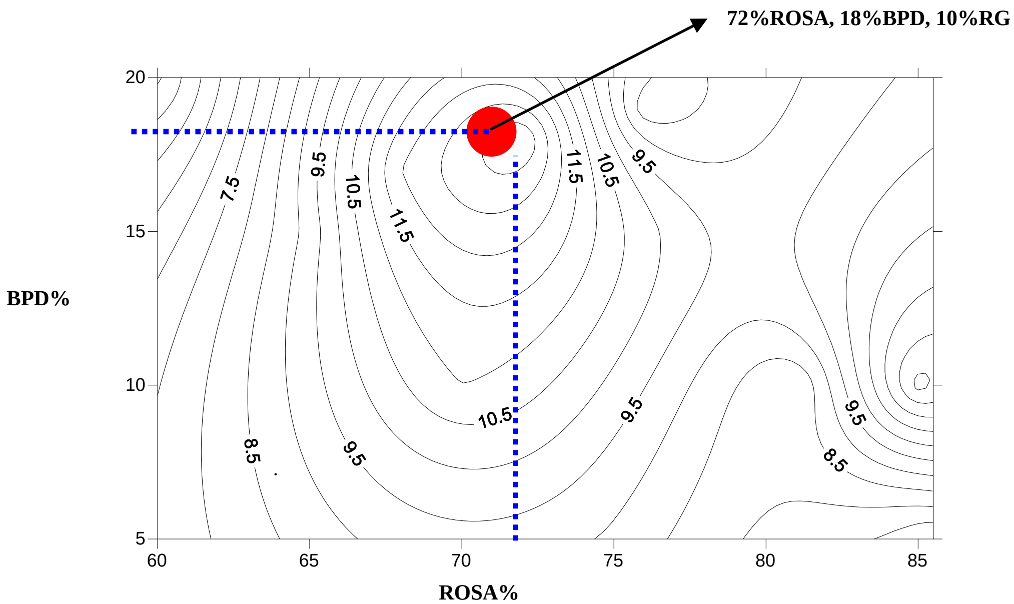

Fig. 6. Compressive Strength of BPD-ROSA-RG Mixes (28days)

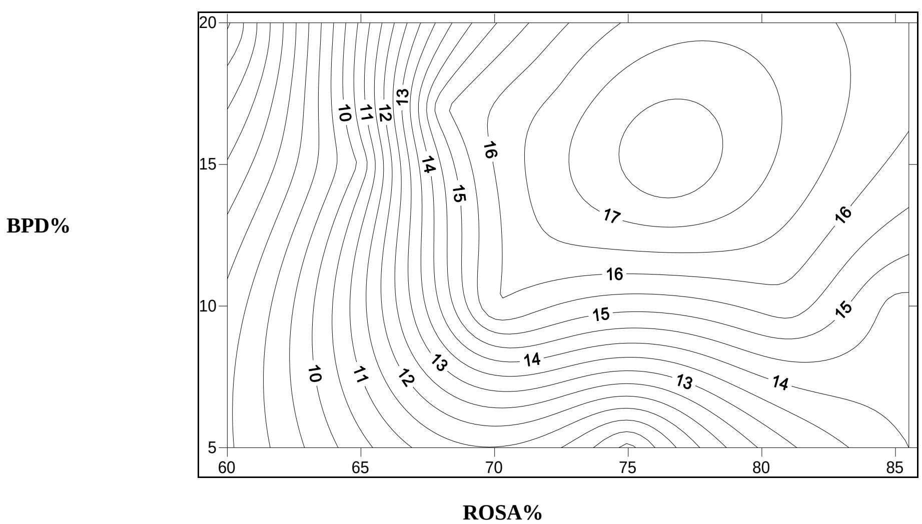

Fig. 7. Compressive Strength of BPD-ROSA-PG Mixes (28days)

Effect of Source of Waste Products on Specimens' Characteristics

The results of compressive strength testing of the specimens showed that Rugeley ash type (I) had more reactivity with BPD and PG at early age (3 days). The compressive strength of the specimens using Rugeley ash type (II) was almost twice more than that of Rugeley ash type (I).

This was because of high lime content (CaO) in Rugeley ash type (I) which is the reason why type C fly ash with high lime content showed more pozzolanic activity than fly ash type F.

Rugeley ash type (II) needed more w/b and its density was lower than Rugeley ash type (I). Obviously the benefit was in using more binder in concrete without increasing the product's density.

Rugeley ash type (I) was brown in colour, which could have been due to higher Fe_2O_3 content. Rugeley ash type (II) was grey.

Ratcliff ashes had similar physical and chemical characteristics with grey colour. Their reactivity was the same and their compressive strength was close to each other.

Similar differences were observed by changing the source of BPD. Tables 4, 5, and 6 show the effects that different types of fly ash and BPD had on the compressive strength of the samples. They also illustrate that the compressive strength of mixes with same material from different sources show more difference in early ages especially at 3 days which should be considered if these materials will be used in low strength concrete.

Additionally, because of their low density, all mixes could be used as light weight cementitious materials in the construction industry.

Table 4. Effect of ROSA from Same Source and Different Batches on Specimens [Karami, 2009]

Mix	Aggregate /Cement	Cement Kg/m^3	Density Kg/m^3	w/b	3 days CS MPa(50 mm)	7 days CS MPa(50 mm)	28 days CS MPa(50 mm)
60%ROSARu(I),-20%BPD(I)-20%PG	275	1103	1820	0.25	5.25	6.15	9.5
60%ROSARU(II)-20%BPD(I)-20%PG	275	1103	1750	0.25	2.4	4.3	8.3

*w/b was reduced from 0.3 to 0.25 to have better comparison especially at 3 days RU=Rugeley Ash

Table 5. Effect of BPD from Same Source and Different Batches on Specimens [Karami, 2009]

Mix	Aggregate /Cement	Cement Kg/m^3	Density Kg/m^3	w/b	3 days CS MPa (50 mm)	7 days CS MPa (50 mm)	28 days CS MPa (50 mm)
60%ROSARu(II)-20%BPD(I)-20%PG	275	1103	1750	0.25	2.4	4.3	8.3
60%ROSARU(II)--20%BPD(II)-20%PG	275	1103	1560	0.25	1.52	2.64	8.8

RU=Rugeley Ash

Table 6. Effect of ROSA Source on Compressive Strength and Density of Specimens [Karami, 2009]

Mix	Aggregate /Cement	Cement Kg/m^3	Density Kg/m^3	w/b	3 days CS MPa(50 mm)	7 days CS MPa(50 mm)	28 days CS MPa(50 mm)
60%ROSARA+20%BPD+20 %PG	267	1067	1670	0.25	0.65	1.51	8.5
60%ROSARU(II)+20%BPD +20%PG	267	1067	1667	0.25	1.6	2.75	9.3

RA=Ratcliff Ash RU=Rugeley Ash

CONCLUSION

The main conclusions from this research project are:

- It is possible to use the sulphate activation properties of Run of Station Ash blend with Red-Gypsum, Plaster Board Gypsum and By-Pass Dust to produce cementitious mixes which could be used as low strength construction materials.
- Increasing ROSA content increased the flow in binary and ternary mixes.
- ROSA-BPD combination had a higher compressive strength than other by-product combinations.

- By-product materials with the same name from different sources or batches have different characteristics which affect mixture properties.
- The mixtures' compressive strength increased with time which is similar to what happens in Portland cement mixes. This allows these industrial by-products to have wider applications in the civil engineering industry.

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