

Performance of Fly Ash and Stone Dust Blended Concrete in Acidic Environment

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Abstract

Large scale housing construction activities require a huge amount of resources. Out of the total cost in a construction project the component of material cost has a major share. Therefore, the need of the hour is the replacement of costly and scarce conventional building materials by innovative, cost effective and environmental friendly alternatives. Fly ash and stone dust, generated as waste products in coal based thermal power plants and stone crusher industry respectively have been found appropriate for this purpose. The objective of this study was to investigate the performance of concrete mixes blended with fly ash and stone dust in chemically aggressive environmental conditions. The results indicate that a judicious selection of these waste products as ingredients in concrete shall further enhance benefits under aggressive environmental conditions of exposure.

Keywords: Fly Ash, Stone dust, Acidic Environment, Blended Concrete, Waste Products

1. Introduction

Concrete is many times exposed to aggressive chemical environments by coming in contact with acidic effluents in industry and sewage in underground pipes. Concrete is basically alkaline in nature and is also susceptible to acidic gases in the atmosphere, especially in and around urban industrial centers. The gaseous pollutant and particulates have a variety of damaging effects on concrete. Out of various gases present in atmosphere, the sulphurous ones have been found to be the most dangerous for calcareous materials such as cement mortar and concrete. Cohen and Bentur [1] have described the effect of sulfates on concrete as complex and Neville [2] has described the situation of the state of understanding in this respect as a confused one. Use of many environmentally polluting waste products such as fly ash and stone dust in construction industry has been gaining wide acceptance.

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Mineral additives, which are pozzolanic in nature, densify the matrix and improve the interface of cement paste & aggregates and improve the performance of concrete in sulfate acidic environments. Kumar and Rao [3] have observed the effect of aggressive chemical environment on the setting time of cement and strength of concrete. They have reported that the setting times increase with the concentration of sulphate ions. This may be due to reduction in solubility of cement paste ions in presence of strong anions in solution (i.e., SO_4^{2-}).

The loss in compressive strength of concrete cubes cured under different types of sulphates was observed with the passage of time. Tikalsky and Carrasquillo [4] have carried out the experiments to observe the influence of fly ash on the sulphate resistance of concrete and explained the dilution effect and pozzolanic effect of fly ash in cement. The fly ashes with a low amount of calcium hydroxide and amorphous calcium aluminate decrease the susceptibility of concrete to sulphate attack. Kumar and Rao [5] presented the results of experimental investigation showing the effect of sulphates on the strength of concrete under the conditions simulating cast in situ and precast situations. They concluded that the use of precasting in place of cast in situ is preferable in situations exposed to sulphate environments.

Wang [6] has carried out the experiments on hardened cement paste specimens made with different cement types and varying water-cement ratios. These specimens were immersed in 5% sodium sulphate solution maintained at constant pH value of 6. The mechanism of sulphate attack is evaluated with the help of XRD analysis in regard to leaching of $\text{Ca}(\text{OH})_2$ and formation of gypsum and Ettringite. O.S.B. Al-Amoudi et al. [7] have observed the effect of magnesium sulphate and sodium sulphate on durability performance of plain and blended cements. It was observed that the deterioration of blended cement exposed to sodium sulphate environment is less. This is attributed to reduced quantity of calcium hydroxide which significantly mitigates the sulphate attack in these cements. Kumar and Rao [8] have carried out the compressive strength test on cubes exposed to time varying sulphate environment and measured cumulative damage to the material. Lawrence [9] has observed the types of disruption during sulphate attack on mortars and concretes and explained the chemical processes involved. It was concluded that partial replacement of ordinary Portland by various latent hydraulic binders can lead to improved sulphate resistance. Camps et al. [10] have observed the influence of surface absorption on sulphate attack and reported the sorptivity of mortar to be sensitive to the condition of cure and type of mortar skin in contact with the fluid. The influence of cure has a dominant effect on the capillarity of mortar which was reflected in the variation of porosity and strength. Rasheeduzzafar et al. [11] have reported the influence of cement composition on the corrosion of reinforcement and sulphate resistance of concrete. The $\text{C}_3\text{S}/\text{C}_2\text{S}$ ratio of cement has been shown to have a significant effect on sulphate resistance of the cement. Building Research Establishment digest [12] discussed the factors responsible for sulphate attack on concrete below the ground level and recommended that suitable selection of cement type and concrete quality are important factors in resisting attack by naturally occurring sulphates.

Mehta [13] has carried out a laboratory investigation involving 16 fly ash samples of varying calcium content with the objective of clarifying the relationship between fly ash composition and sulphate resistance. The results show that rather than the chemical composition it is the mineralogical composition of cement fly ash interaction product that controls the sulphate resistance. Shukla et al. [14] have reported that the compressive strength of concrete increases with an increase in percentage replacement of sand by stone dust up to a percentage of about 40% and thereafter it reduces. Kumar [15] has studied the strength of fly ash blended cement concrete in marine environment. The blending of fly ash (10% and 20%) in both Type I and Type II cements has increased their resistance against seawater attack. Several aspects related with the utilization of fly ash in concrete in sulfate aggressive environments have been examined [16,17,18]. Research and field data on the effects of pozzolanas on durability and service life have been considered to be incomplete or at best inconclusive. Use of stone dust also has been found effective in improving the

strength of concrete. On the basis of literature review it may be suggested that the cement can be replaced upto 30% by fly ash and sand up to 40% by stone dust effectively. Use of super plasticizers also is required from the point of view of workability and strength of the blended concrete.

The objective of this study was to investigate the performance of concrete mixes blended with fly ash and stone dust in acidic sulphate environmental conditions. Normal concrete mix of strength grade 25 N/mm² and concrete mixes of the same grade blended with fly ash and / or stone dust and super plasticizers were tested under normal water curing and varying sulphuric acid concentration conditions up to 180 days. In this paper, performances of these mixes have been compared primarily on the basis of loss of compressive strength and residual compressive strength with time. The results indicate that a judicious selection of these waste products as ingredients in concrete is beneficial under aggressive environmental conditions of exposure.

2. Experimental Program

2.1 Materials

The cement used for investigation was ordinary Portland cement of Type I. The fly ash used for the investigation was procured from Indraprastha thermal power plant located in New Delhi, India. The physical and chemical properties of cement and fly ash are exhibited in Table 1. As a fine aggregate, sand obtained from the river Yamuna was used without any refinement. Stone dust of the Granite stone was procured from Goramachhia near the city of Jhansi in the state of Uttar Pradesh of India. The coarse aggregate was crushed granite of maximum size 20 mm. It was of angular shape and rough texture. Both the coarse and fine aggregates were thoroughly washed to remove dust as well as sulfates and chlorides, if any. The properties of stone dust and coarse & fine aggregates are shown in Table 2. The water used for mixing and curing was potable tap water free from organic and suspended impurities. The super plasticizer used was high molecular weight condensates of naphthalene formaldehyde polymer of brown colour and specific gravity 1.22. This has been found compatible with the cement used for the investigation. On the basis of chemical composition the potential composition of ordinary Portland cement was worked out using Bogue's equations and the percentages by weight of cement of C₃S, C₂S, C₃A and C₄AF were found to be 53.72, 22.58, 9.59 and 7.54 respectively.

2.2 Mix Proportions and Aggressive Environment

The concrete mix design was carried out for strength grade 25 N/mm² in which the cement, sand and coarse aggregates were proportioned in the ratio 1:1.3:2.5 with w/c 0.50. The details of mix designation are shown in Table 3. The dosage of superplasticizer was decided on the basis of Marsh cone test. In case of blended concretes, 1% superplasticizer by weight of cement was used to maintain the desired workability. In order to observe the effect of sulphuric acid on concrete specimens, one curing tank with ordinary water and two curing tanks of sulphuric acid having concentrations 0.1 N and 0.2 N respectively were prepared. Due precautions were taken while mixing sulphuric acid to water in the curing tanks and the concentration of the acid was maintained throughout the curing period.

The mixing of concrete was carried out in a power-driven mixer and 150 mm size concrete cubes were cast for each mix using a table vibrator. The moulds were stripped off after one day and cubes were immersed in each type of curing tank. After 28, 90 and 180 days curing, cubes from each tank were taken out and after air-drying they were tested for compressive strength. The

strength test was carried out in a universal testing machine maintaining the rate of loading as 1.25 mm/ minute.

Table 1: Properties of Cement and Fly Ash

S.N.	Properties	Cement	Fly Ash
Physical Properties			
1.	Fineness – Blain's (m ² /Kg)	280	300
2.	Specific gravity	3.15	1.99
3.	Moisture content (%)	--	0.26
4.	Normal consistency (%)	36.00	--
5.	Setting times (minutes)		--
	Initial	85	
	Final	300	
6.	Compressive strength (N/mm ²)		
	3 days	24.60	--
	7 days	36.20	--
	28 days	49.10	--
7.	Soundness – Le Chatelier (mm)	0.70	--
Chemical Properties (% by weight)			
8.	Silicon dioxide	19.87	40.2
9.	Calcium oxide	62.14	12.9
10.	Aluminum oxide	4.42	21.02
11.	Ferric oxide	3.01	11.7
12.	Magnesium oxide	2.91	2.43
13.	Sulphur trioxide	3.25	2.25
14.	Loss on ignition	2.4	2.29

Table 2: Properties of Aggregates

S.N.	Properties	Stone Dust	Fine Aggregate	Coarse Aggregate
1.	Specific gravity	2.74	2.63	2.65
2.	Water absorption (%)	2.14	1.68	0.54
3.	Fineness Modulus	2.55	3.05	7.4

Table 3: Mix Designations

S.N.	Mix Designation	Proportions
1.	A	M 25 concrete
2.	B	40% replacement of sand by stone dust in Mix A
3.	C	30% replacement of cement by fly ash in Mix A
4.	D	40% replacement of sand by stone dust and 30% replacement of cement by fly ash in Mix A

3. Results & Discussion

The cubes were taken out from various tanks after the completion of required curing time. The result of compressive strength of cubes of different mixes cured in ordinary water and sulphuric acid with concentration 0.1 N and 0.2 N for different curing periods are shown in Table 4.

Table 4: Compressive Strength of Cubes of Different Mixes

Age (Days)	Mix Designations	Compressive Strength (N/mm^2)				Reduction in Compressive Strength (%)	
		In Ordinary Water	In Sulphuric Acid With Concentration		In Sulphuric Acid With Concentration		
			0.1 N	0.2 N	0.1 N	0.2 N	
28	A	36.0	35.28	33.90	2.0	3.9	
	B	39.5	38.59	36.85	2.3	4.5	
	C	33.0	32.50	31.46	1.5	3.2	
	D	35.4	34.65	33.8	2.1	4.5	
90	A	38.5	36.76	34.63	4.5	5.8	
	B	41.4	39.33	36.85	5.0	6.3	
	C	34.0	32.87	31.23	3.3	5.0	
	D	37.6	35.98	34.48	4.3	8.3	
180	A	42.0	38.47	34.62	8.4	10.0	
	B	43.0	38.95	34.78	9.4	12.0	
	C	35.5	33.01	30.37	7.0	8.0	
	D	41.2	38.61	35.95	6.2	12.7	

Before being tested for compressive strength the samples were visually examined. It was seen that visual effects in samples were the least in the case of water curing. These were the most obvious in the case of 0.2 N concentration of the acidic environment. Most of the samples showed efflorescence on their surfaces, with time, in the acidic environment. With the advancement of age, some of the samples were observed to have broken corners and edges. This effect was more prominent in the case of fly ash blended concrete mix samples. In acidic environments, some samples developed brown colour patches on their surfaces with time. This effect could be more clearly seen in the higher concentration of 0.2 N. In spite of these effects, samples could largely retain their structural integrity and shape throughout the duration of study.

Figure 1 shows variation of compressive strength of concrete cubes of different mixes cured in fresh water with age. The compressive strength of concrete cubes increases with age of concrete. The 90 days and 180 days compressive strengths are approximately 7.0% and 16.7% more than 28 days strength for the mix A, 4.8% and 8.86% for mix B, 3.0% and 7.58% for mix C and 6.2% and 16.38% for mix D. The percentage wise development of strength with time in ordinary water is similar for Mix A and Mix D and it is better for these compared to Mix B and Mix C.

The percentage increase of compressive strength remained positive for Mix A and Mix D for all curing environments in the duration of study. It is not so for Mixes B and C. Out of Mix A and Mix D, a larger rate of strength increase in all curing environments is reported by Mix D. The 90

days and 180 days compressive strengths are approximately 3.8% and 11.4% more than 28 days strength for 0.1N acidic environment and 2.9% and 6.4% more than the respective 28 days strength for 0.2N acidic environment for the Mix D. Respective values for the Mix A are 4.2% and 9% for 0.1N acidic environment and 2.2% and 2.1% for the 0.2N acidic environment.

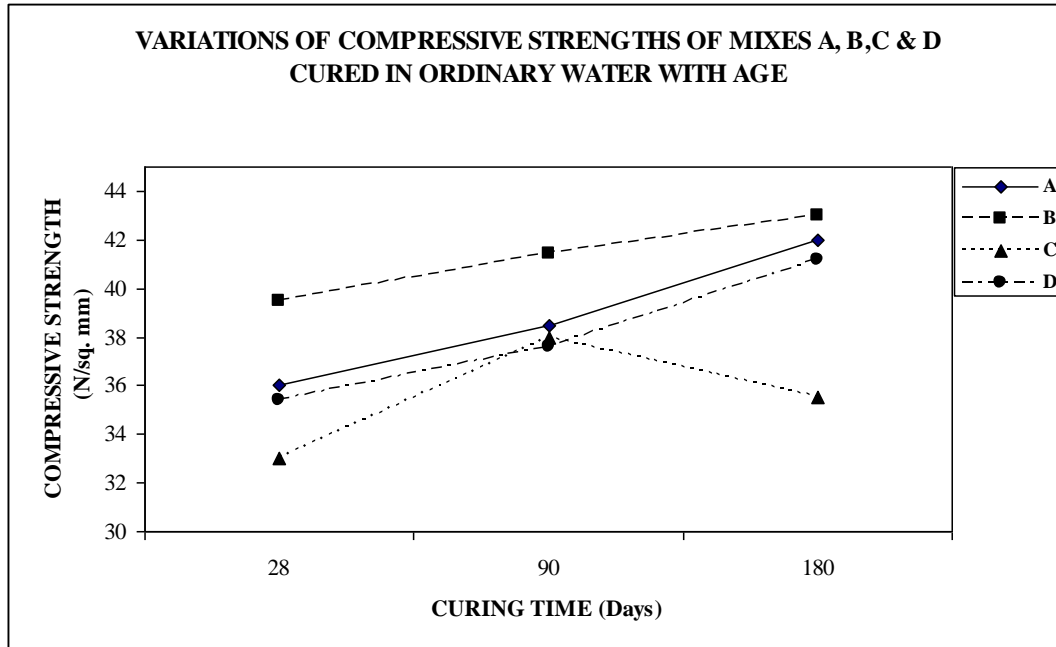


Figure 1: Variations of compressive strengths of different mixes with age

Figure 2 shows the loss in compressive strength of concrete cubes cured in acidic solution of various concentrations with age. The percentage loss in compressive strength at any age is estimated with reference to the strength of controlled concrete specimens in ordinary water at that age. It is seen that the loss in compressive strength of samples increases with sulphate ion concentration and age. This is due to the fact that acidic solution reacts with C_3A as well as C_3S compounds of cement. The more the concentration of the acidic solution, the formation of ettringite and gypsum is also more which results into the increased disintegration / deleterious effect.

In those mixes which were prepared by using stone dust, the loss of compressive strength increases with sulphate ion concentration and age. It is clear that the loss of strength in concrete with 40% replacement of sand is comparable to concrete made with only sand. But the addition of stone dust by replacing 40% sand increases the compressive strength of concrete. Hence the residual strength of the concrete after deducting the losses is still higher in concrete prepared with the stone dust.

The loss in compressive strength of concrete blended with fly ash is less compared to that of plain concrete at any age. It may indicate improved durability of fly ash blended concrete against the attack of sulphuric acid due to the dilution effect and pozzolanic effect. The dilution effect can be understood as the reduction in C_3A of the cement due to 30% replacement of cement by fly ash. The pozzolanic effect is due to the interaction between fly ash and calcium hydroxide, a byproduct of ordinary Portland cement. A refined calcium silicate hydrate binder matrix is formed. As a result, concrete becomes less permeable and the excess calcium present in fly ash is consumed and rendered unavailable to expansive formation of ettringite or gypsum compounds.

In case of the concrete blended with fly ash and stone dust the loss in compressive strength was observed which increases with curing time as well as the concentration of the sulphate ions. These losses in compressive strength at any particular age and concentration of sulphate ions are more than that of concrete blended with only the fly ash. This may be due to the conjoint effect of fly ash and stone dust. However, the residual strength in this case is comparable with that of plain concrete at the age of 180 days curing.

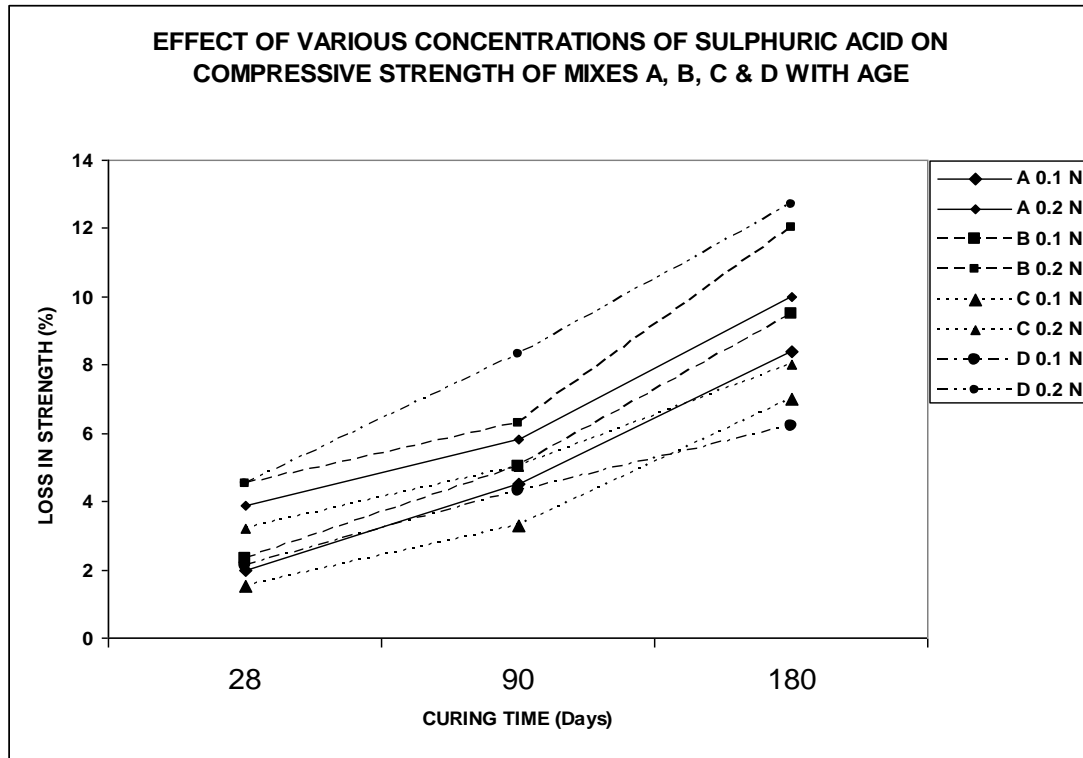


Figure 2: loss in compressive strengths of different mixes in acidic environments

To gain further insight into the trends of strength development of various types of plain and blended concrete mixes in acidic environments and to investigate into their respective performances, trend lines of strength developments of various mixes in different curing environments were drawn. These are shown in Figures 3, 4 and 5.

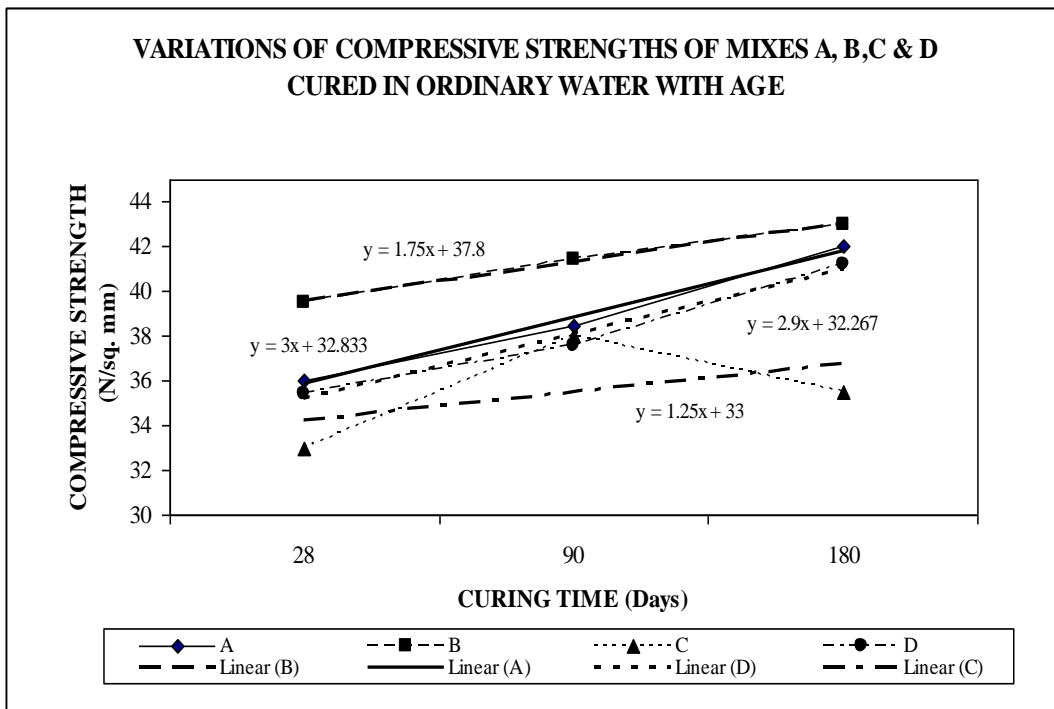


Figure 3: Trend lines for variations of compressive strength of mixes in ordinary water environment

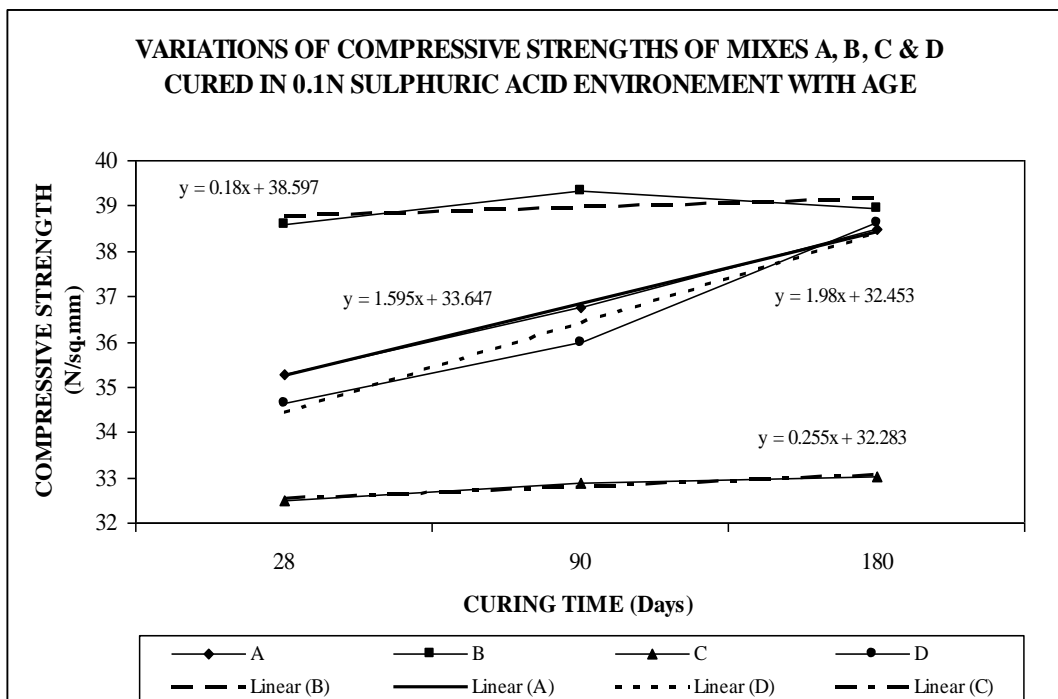


Figure 4: Trend lines for variations of compressive strength of mixes in 0.1N sulphuric acid environment

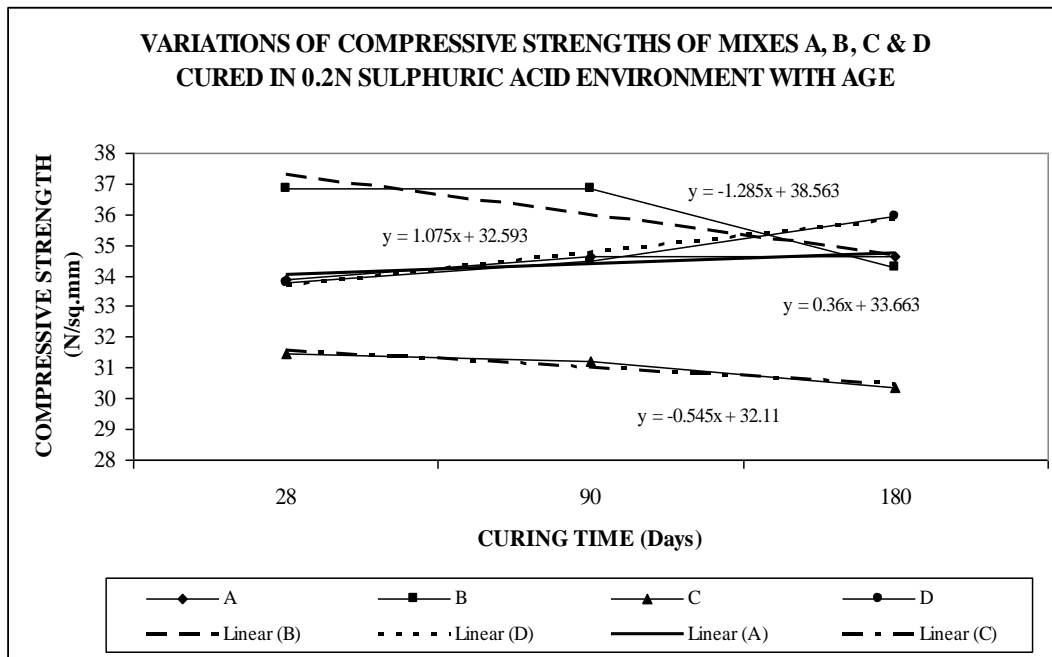


Figure 5: Trend lines for variations of compressive strength of mixes in 0.2N sulphuric acid environment

When slopes of these trend lines were considered, it was appreciated that slopes of these trend lines indicate the performance of these mixes in terms of strength development. A higher positive slope of a trend line of strength development with age in an environment would suggest a higher rate of strength development. Slopes of these trend lines are taken from their equations shown in Figures 3, 4 and 5. These equations are written in $y=mx+c$ format where ‘m’ indicates the slope of the trend line. These values of slopes of trend lines are given in Table 5.

Table 5: Slopes of trend lines of strength development of different mixes

Name Of Mix	In Ordinary Water (Case 1)	In 0.1 N Acidic Environment (Case 2)	In 0.2 N Acidic Environment (Case 3)
A	3	1.595	0.36
B	1.75	0.18	-1.285
C	1.25	0.255	-0.545
D	2.9	1.98	1.075

It is seen that slopes of trend lines of strength development for all mixes in ordinary water (Case 1) and in 0.1 N acidic environment (Case 2) remain positive. When this is seen for 0.2 N acidic environment (Case 3), the slope is not positive for all the mixes. It remains positive for mixes A and D while becoming negative for mixes B and C. It indicates that type of environment (considering Case 1 and Case 3) and concentration of acidic environment (comparing Case 3 with Cases 1 and 2) is an important factor in the development of compressive strength of concrete. For Case 3 the slopes of trend lines of strength development are negative for Mixes B and C while these are positive for Mixes A and D. It shows better performance of Mixes A and D compared to Mixes B and C in terms of strength development for this case. For Cases 1 and 2 while the slopes of trend lines do not become negative, their slopes may still indicate relative performances of these mixes. It is clear that strength development is better for Mixes A and D for the case 1 while it is worst for the Mix C. It

may indicate a better strength increase for Mix B compared to Mix C due to a better filling of pore spaces by fine particles of stone dust and their shape and surface texture.

For the Case 2 the group of Mixes A and D still remain better than that of Mixes B and C. But relative positions of mixes giving a better performance are interchanged in both the groups. For this case, Mix D becomes the best one while Mix C becomes better than Mix B possibly because of benefits of pozzolanic reactions. It definitely indicates that nature of the concrete mix (e.g., containing fly ash) is an important factor in its performance in aggressive environment. The beneficial effect of the use of fly ash and stone dust is best seen in Case 3 where the slope of the trend line of strength development is the maximum for Mix D. Therefore, the utilization of stone dust as inert material and fly ash as a reactive material is beneficial especially when the concrete is exposed to the attack of aggressive environmental conditions such as acids containing sulphate ions.

4. Conclusion

On the basis of the experimental study the following conclusions are drawn.

- 1 The effect of the sulphuric acid environment on concrete is to decrease its compressive strength and this loss increases as a function of sulphate ion concentration and age of exposure.
- 2 The concrete blended with stone dust shows more loss of strength compared to plain concrete when exposed to acid environment. But the residual strength of concrete blended with stone dust is more than that of plain concrete.
- 3 The development of compressive strength of concrete blended with fly ash with age of curing is less compared to that in plain concrete. However, the concrete blended with fly ash shows less loss of strength compared to concrete blended with stone dust, when exposed to acid environment.
- 4 The residual strength of concrete blended with fly ash and stone dust is comparable with that of plain concrete at any age. Thus durable concrete can be made by replacing sand with stone dust up to 40% and cement with fly ash up to 30%. Hence stone dust and fly ash can be utilized effectively in making the durable concrete structures

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