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# STUDIES ON FLY ASH CONCRETE UNDER SULPHATE ATTACK IN ORDINARY, STANDARD AND HIGHER GRADES AT EARLIER AGES

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## ABSTRACT

This paper presents a detailed experimental study on sulphate ion attack on ordinary, standard and higher grade concretes at early ages i.e. 7 days and 28 days. The main variable investigated in this study is percentage variation of fly ash. The cement is replaced by fly ash up to 40% at a regular interval of 10%. The compressive strength and weight loss were studied. Test results indicate that use of fly ash in concrete has improved performance against sulphate attack in all the three grades of concrete. A simple empirical equation has been proposed to study the behavior of concrete under acid attack using best fit method.

## 1. INTRODUCTION

Ordinary Portland cement is the most commonly used building material throughout the world and it will retain its status in near future also because of demand and expansion of construction industry all over the world. Further the greatest challenge before the concrete construction industry is to serve the two pressing needs of human society, namely the protection of environment and meeting the infrastructure requirements of our growing population Structures which are constructed in the marine areas are liable to be subjected to acidic attack. One of such major problems is sulphate ion attack against concrete structures.The weight loss and deterioration of concrete under such attack needs investigation and an alternate solution should be brought out. It is in this context the protection and enhancement of durability of concrete assumes importance. It has been recognized for a long time that sulphate ions particularly in soil and water cause severe damage to concrete structures. There have been numerous field studies on the distress caused to concrete structures generated by sulphate attack. Sulphate attack has often been discussed in the terms of reaction of cement hydrate with sulphate ions. The

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superior resistance of the concrete mix against sulphate attack can be brought in by the pore refinement process and densification of transition zone occurring due to conversion of lime forming from the hydration of cement in to additional binding material through pozzoalnic activity [1-2]. One of the main causes of deterioration in concrete structures is the distress of concretes due to its exposure to harmful chemicals that may be found in natures, such as in contaminated ground waters, industrial effluents and sea waters. The most aggressive chemicals that effect durability of structures are chlorides and sulphates [3]. Many research studies have also been carried out to unravel this complex phenomenon through immersion tests in the laboratory as well as in field [4-5]. In recent years the use of blended cements particularly the fly ash based variety has shown a sharp increase. This is mainly on the account of ecological benefits and the improvements in the long-term durability of concrete. Generation of fly ash in huge quantities as a byproduct in the coal based electric power plants poses gigantic problem in its disposal. Fly ash is a great environmental threat. Disastrous effects of ever increasing quantities of fly ash have to be brought under control. Fly ash is now being used in cement as a supplementary cementetious material. The present paper discusses the effect of sulphate attack on High Volume Fly Ash concrete in Ordinary, Standard and higher grades.

## 2. EXPERIMENTAL INVESTIGATION

In order to decide the maximum amount of fly ash to be added, an experimental study was carried out at various percentage replacements i.e. from 0% to 40% at regular increment of 10% for compressive strength of concrete. The locally available construction materials such as coarse aggregate, fine aggregate were chosen. The OPC confirming to 53 grade was used in this study. The fly ash has been procured from VTPS Vijayawada(India). The physical and chemical analysis of fly ash is also done and results were correlated with IS 3812-1981. The percentages of various oxides present in fly ash (used in the experimental work) after Chemical analysis (testing) are shown in Table 1. The Sulphuric acid ($H_2SO_4$.) with 5% concentration was used in the investigation.

The sand used in experimentation is from the local river source and confirming to zone II (I.S 383). Coarse aggregate of maximum size 20mm from the local crusher has been used. The grades of concrete mixes used in the present study were M25,M45 andM60. All the mix proportions were designed using I.S.10260-1982.The cubes are of 150 mm x 150 mm x 150 mm were cast and tested. A total number of 90 cubes were cast.

The cubes were cured in separate tanks containing 5% $H_2SO_4$ and potable water for 28 days completely. The weights were taken initially at time of immersing in acid and at 7 days, and 28 days of curing. The percentage weight Loss during curing period was observed. The comparison between loss of weight of cubes immersed in acidic water with different percentages of fly ash in different Grades were made. The 28 days compressive strength of cubes under acid water curing were also evaluated and the results are tabulated in Table 2.

Table 1. Chemical composition of Fly Ash

| Criteria | Values |
|---|---|
| Specific surface | $5840cm^2/gm$ |
| Specific gravity | 2.4 |
| Silica | 58.14wt% |
| Alumina | 28.98wt% |
| Ferric oxide | 4.90wt% |
| Calcium oxide | 5.68wt% |
| Magnesium oxide | 1.04wt% |
| Sulphur trioxide | 0.64wt% |
| Loss on ignition | 0.54wt% |
| Insoluble Residue | 84.44% |

Test Results: Table 2. Concrete cubes of mix 1: 1.42: 3.9: 0.46are cured in $H_2SO_4$: (Ordinary Grade)

| Designation | Initial Weight of Concrete Cube in kgs | Weight of cube after 7 days of curing in kgs | Percentage weight loss | Weight of cube after 28 days of curing in kgs | Percentage weight loss |
|---|---|---|---|---|---|
| $A_0$ | 8.320 | 8.110 | 2.520 | 7.998 | 3.870 |
| $A_{10}$ | 8.285 | 8.100 | 2.232 | 7.988 | 3.584 |
| $A_{20}$ | 8.370 | 8.255 | 1.373 | 8.147 | 2.664 |
| $A_{30}$ | 8.230 | 8.175 | 0.668 | 8.020 | 2.511 |
| $A_{40}$ | 8.195 | 8.175 | 0.244 | 8.036 | 1.940 |

| Designation | 28 day Compressive Strength in 5% $H_2SO_4$ curing $N/mm^2$ | Percentage increase when compare to 0% fly ash concrete |
|---|---|---|
| $A_0$ | 20.00 | 0.00 |
| $A_{10}$ | 22.20 | 11.1 |
| $A_{20}$ | 24.40 | 22.0 |
| $A_{30}$ | 26.20 | 31.0 |
| $A_{40}$ | 21.50 | 7.5 |

## 3. DISCUSSION

Sulphate attack on Portland cement matrix is generally characterized by sulphate ions with cement hydration products, which causes expansion, cracking and spalling as well as loss of mass and strength. Numerous studies to minimize the attack and prolong the service life of concrete structures exposed to sulphate environments have been carried out. All these studies show that sulphate attack is the result of complex set of chemical processes and that there is a still lot of controversy about the mechanism of such attack. From the visual examination it is clear that the specimen subjected to sulphate attack behave very differently and also degree of deterioration is high. Weight Loss is phenomenon where loss of weight is due to penetration of acid ions into concrete and the internal ettringite zone will get effected. To arrest the Acid ion penetration into concrete Flyash has been introduced. It is clear from the investigation the percentage weight loss is decreased even at fly ash replacement is up to 40% in all three grades i.e., Ordinary, Standard, and Higher grades. The compressive strength at 28 days is observed increasing up to 40% replacement of cement by Fly ash in ordinary grade concrete. In standard grade concrete, the compressive strength increased consistently up to 40% replacement of cement by fly ash. In higher grades, the compressive strength observed increasing up to 10% replacement of cement by fly ash, but at higher replacements the compressive strength observed decreasing. At 28 days the weight loss in conventional concrete under 5% $H_2SO_4$ is about 3.84% whereas for 40 % fly ash concrete is around 1.94% in ordinary grades. In standard grade, the weight loss in conventional concrete at 28 days is 3.464% and when fly ash was replaced the percentage weight loss came down to 1.235 at 40 % replacement of cement by fly ash. A Simple empirical equation has been proposed to study the behavior of concrete in sulphate environment. The equation proposed is in the Following form

$$Y=a\,e^{-bx}$$

Where Y= Percentage Weight Loss.

a,b are Constants.

X=percentage of Fly ash.

The proposed equation has shown good correlation with the observed values.

Figure (a), Figure (b) shows the correlation between Experimental values and Proposed theoritcal values.

## 4. CONCLUSIONS

1. After 28 days of immersion of concrete cubes in 5% concentrated $H_2SO_4$, the concrete with 40%Fly ash has shown a better performance in Ordinary and Standard grades.
2. In the initial stages like 7 days the weight loss in concretes observed very less as fly ash replacement is increasing.
3. From compressive strength point of view, the investigations have showed an improvement in fly ash concretes over conventional concretes in all the Three Grades. Therefore replacement of cement by fly ash is recommended in sulphate-attacked areas.
4. In higher-grade concretes, there is an improvement in compressive strength upto 10% of replacement of cement by fly ash over Conventional concrete (0% fly ash).

5. In all the three grades Flyash concretes has shown better performance in terms of weight loss over conventional concretes.
6. The proposed Empirical Equation has shown good correlation with Experimental values in all the three Grades.

Concrete cubes of mix 1:1.2:3.0:0.4 are cured in $H_2SO_4$: (Standard Grade)

| Designation | Initial Weight of Concrete Cube in kgs | Weight of cube after 7 days of curing in kgs | Percentage weight loss | Weight of cube after 28 days of curing in kgs | Percentage weight loss |
|---|---|---|---|---|---|
| $B_0$ | 8.140 | 7.975 | 2.020 | 7.858 | 3.464 |
| $B_{10}$ | 8.090 | 8.000 | 1.112 | 7.844 | 3.040 |
| $B_{20}$ | 8.180 | 8.105 | 0.916 | 7.958 | 2.713 |
| $B_{30}$ | 8.105 | 8.090 | 0.185 | 7.944 | 2.026 |
| $B_{40}$ | 8.175 | 8.165 | 0.122 | 8.074 | 1.235 |

| Designation | 28 day Compressive Strength in 5% $H_2SO_4$ curing $N/mm^2$ | Percentage increase when compare to 0% fly ash concrete |
|---|---|---|
| $B_0$ | 24.4 | 0 |
| $B_{10}$ | 28.8 | 18.03 |
| $B_{20}$ | 30.2 | 23.77 |
| $B_{30}$ | 30.6 | 25.41 |
| $B_{40}$ | 28.8 | 18.03 |

Concrete cubes of mix 1:0.9:2.5:0.3 are cured in $H_2SO_4$: (Higher Grade)

| Designation | Initial Weight of Concrete Cube in kgs | Weight of cube after 7 days of curing in kgs | Percentage weight loss | Weight of cube after 28 days of curing in kgs | Percentage weight loss |
|---|---|---|---|---|---|
| $C_0$ | 8.295 | 8.090 | 2.471 | 7.967 | 3.949 |
| $C_{10}$ | 8.310 | 8.130 | 2.166 | 7.986 | 3.893 |
| $C_{20}$ | 8.355 | 8.195 | 1.915 | 8.050 | 3.641 |
| $C_{30}$ | 8.370 | 8.245 | 1.493 | 8.136 | 2.795 |
| $C_{40}$ | 8.290 | 8.180 | 1.326 | 8.060 | 2.774 |

| Designation | 28 day Compressive Strength in | Percentage increase when |
|---|---|---|

| | **5% $H_2SO_4$ curing N/mm$^2$** | **compare to 0% fly ash concrete** |
|---|---|---|
| $C_0$ | 50.6 | 0 |
| $C_{10}$ | 53.5 | 5.76 |
| $C_{20}$ | 45.0 | -11.06 |
| $C_{30}$ | 37.7 | -25.49 |
| $C_{40}$ | 33.7 | -33.39 |

Ordinary Grade Table 3.

| **Designation** | **Cement content (kg/m$^3$)** | **Fly ash (kg/m$^3$)** | **Fine aggregate (kg/m$^3$)** | **Coarse aggregate (kg/m$^3$)** | **Water/cementious ratio** |
|---|---|---|---|---|---|
| PL0 1 | 400 | 0 | 592 | 1560 | 0.48 |
| PL0 2 | 400 | 0 | 592 | 1560 | 0.48 |
| PL0 3 | 400 | 0 | 592 | 1560 | 0.48 |
| PL10 1 | 360 | 40 | 592 | 1560 | 0.48 |
| PL10 2 | 360 | 40 | 592 | 1560 | 0.48 |
| PL10 3 | 360 | 40 | 592 | 1560 | 0.48 |
| PL20 1 | 320 | 80 | 592 | 1560 | 0.48 |
| PL20 2 | 320 | 80 | 592 | 1560 | 0.48 |
| PL20 3 | 320 | 80 | 592 | 1560 | 0.48 |
| PL30 1 | 280 | 120 | 592 | 1560 | 0.48 |
| PL30 2 | 280 | 120 | 592 | 1560 | 0.48 |
| PL30 3 | 280 | 120 | 592 | 1560 | 0.48 |
| PL40 1 | 240 | 160 | 592 | 1560 | 0.48 |
| PL40 2 | 255 | 160 | 592 | 1560 | 0.48 |
| PL40 3 | 255 | 160 | 592 | 1560 | 0.48 |

Standard Grade Table 4.

| **Designation** | **Cement content ($kg/m^3$)** | **Fly ash ($kg/m^3$)** | **Fine aggregate ($kg/m^3$)** | **Coarse aggregate ($kg/m^3$)** | **Water/cementious ratio** |
|---|---|---|---|---|---|
| PM0 1 | 435 | 0 | 522 | 1305 | 0.40 |
| PM0 2 | 435 | 0 | 522 | 1305 | 0.40 |
| PM0 3 | 435 | 0 | 522 | 1305 | 0.40 |
| PM10 1 | 391.5 | 43.5 | 522 | 1305 | 0.40 |
| PM10 2 | 391.5 | 43.5 | 522 | 1305 | 0.40 |
| PM10 3 | 391.5 | 43.5 | 522 | 1305 | 0.40 |
| PM20 1 | 348 | 87 | 522 | 1305 | 0.40 |
| PM20 2 | 348 | 87 | 522 | 1305 | 0.40 |
| PM20 3 | 348 | 87 | 522 | 1305 | 0.40 |
| PM30 1 | 304.5 | 130.5 | 522 | 1305 | 0.40 |
| PM30 2 | 304.5 | 130.5 | 522 | 1305 | 0.40 |
| PM30 3 | 304.5 | 130.5 | 522 | 1305 | 0.40 |
| PM40 1 | 261 | 174 | 522 | 1305 | 0.40 |
| PM40 2 | 261 | 174 | 522 | 1305 | 0.40 |
| PM40 3 | 261 | 174 | 522 | 1305 | 0.40 |

Higher Grade Table 5.

| **Designation** | **Cement content ($kg/m^3$)** | **Fly ash ($kg/m^3$)** | **Fine aggregate ($kg/m^3$)** | **Coarse aggregate ($kg/m^3$)** | **Water/cementious ratio** |
|---|---|---|---|---|---|
| PH0 1 | 475 | 0 | 427.5 | 1187.5 | 0.30 |
| PH0 2 | 475 | 0 | 427.5 | 1187.5 | 0.30 |
| PH0 3 | 475 | 0 | 427.5 | 1187.5 | 0.30 |
| PH10 1 | 427.5 | 47.5 | 427.5 | 1187.5 | 0.30 |
| PH10 2 | 427.5 | 47.5 | 427.5 | 1187.5 | 0.30 |
| PH10 3 | 427.5 | 47.5 | 427.5 | 1187.5 | 0.30 |
| PH20 1 | 380 | 95 | 427.5 | 1187.5 | 0.30 |
| PH20 2 | 380 | 95 | 427.5 | 1187.5 | 0.30 |
| PH20 3 | 380 | 95 | 427.5 | 1187.5 | 0.30 |
| PH30 1 | 332.5 | 142.5 | 427.5 | 1187.5 | 0.30 |
| PH30 2 | 332.5 | 142.5 | 427.5 | 1187.5 | 0.30 |
| PH30 3 | 332.5 | 142.5 | 427.5 | 1187.5 | 0.30 |
| PH40 1 | 285 | 190 | 427.5 | 1187.5 | 0.30 |
| PH40 2 | 285 | 190 | 427.5 | 1187.5 | 0.30 |
| PH40 3 | 285 | 174 | 427.5 | 1187.5 | 0.30 |

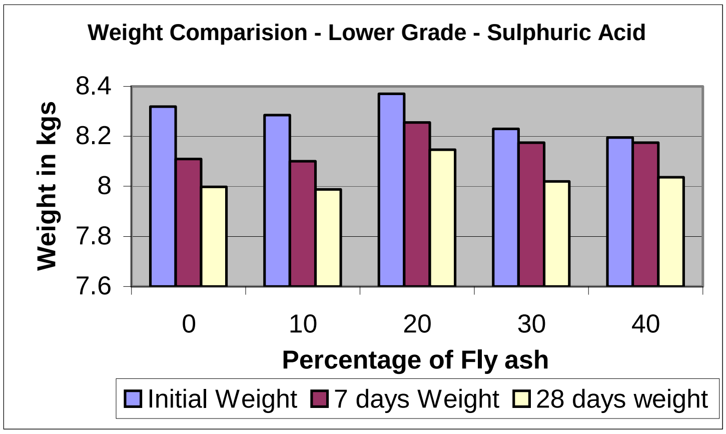


Figure 1.

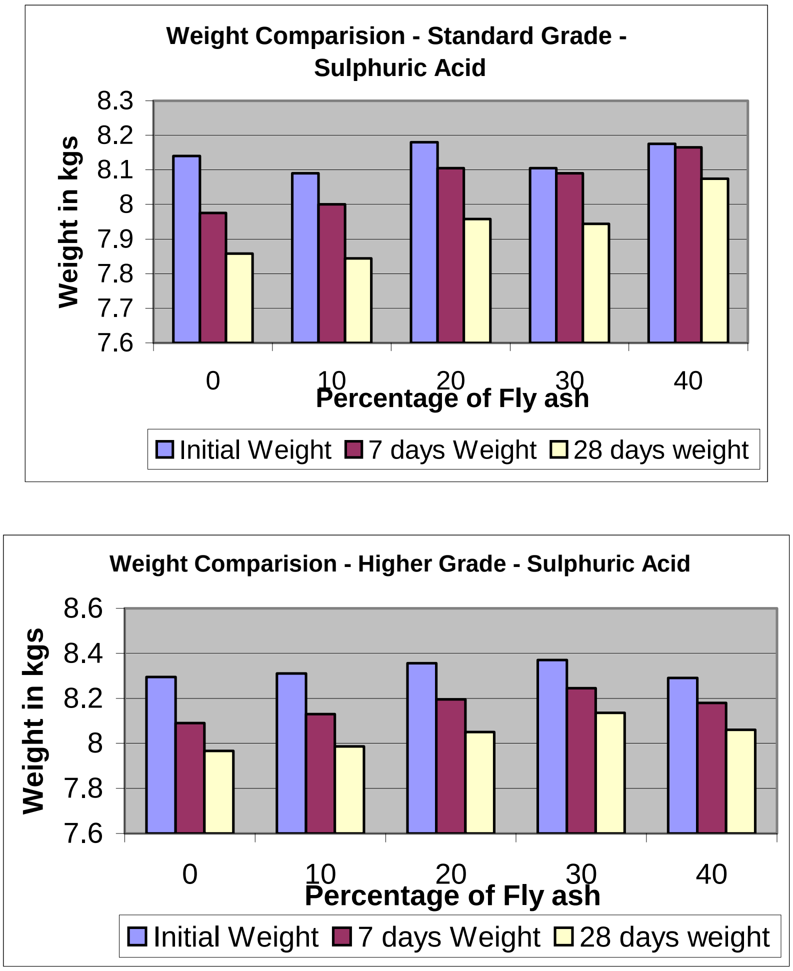


Figure 2.

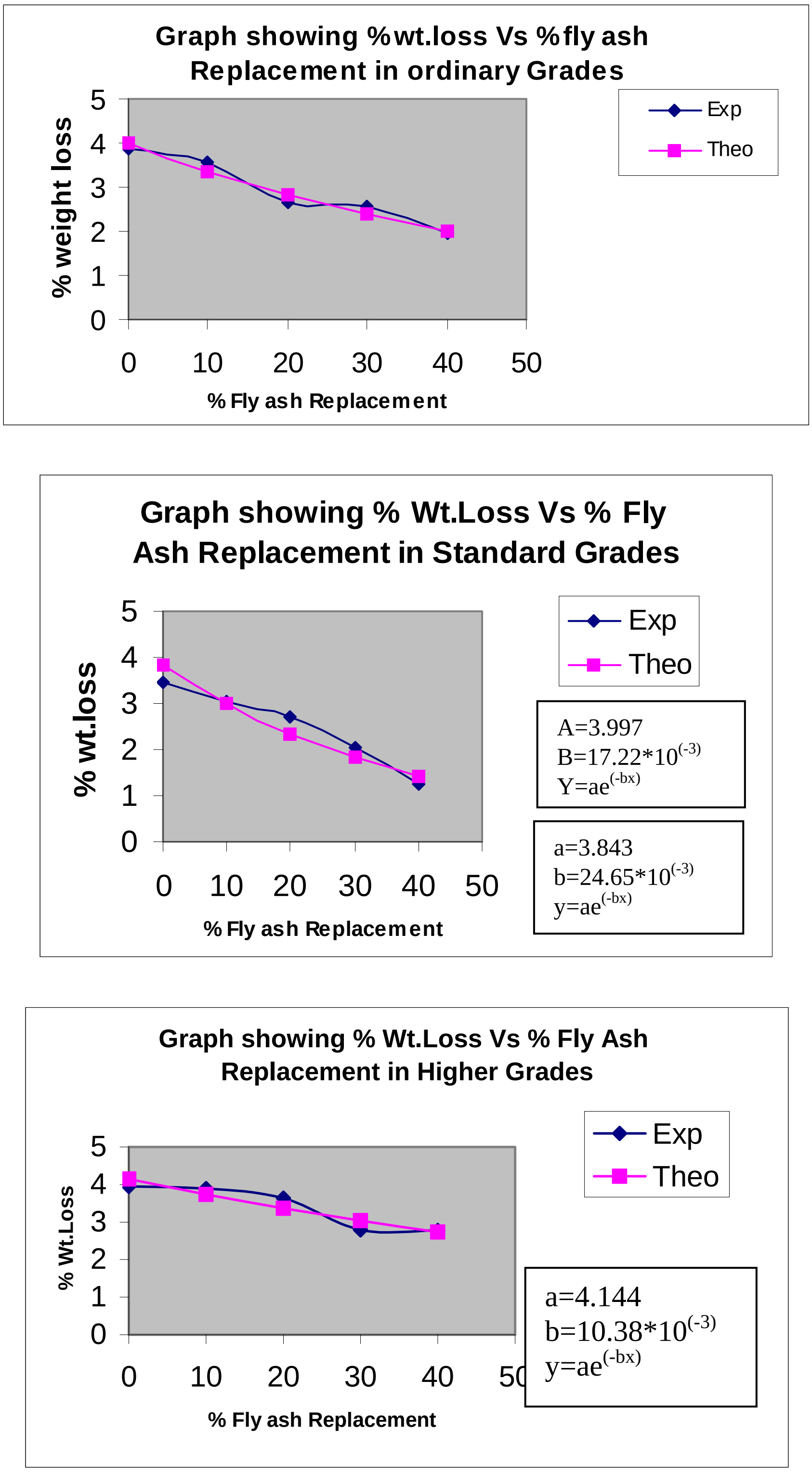
Graph showing %wt.loss Vs %fly ash Replacement in ordinary Grades
% weight loss
% Fly ash Replacement
Exp
Theo
0 1 2 3 4 5
0 10 20 30 40 50
Graph showing % Wt.Loss Vs % Fly Ash Replacement in Standard Grades
% wt.loss
% Fly ash Replacement
Exp
Theo
A=3.997
B=17.22*10^(-3)
Y=ae^(-bx)
a=3.843
b=24.65*10^(-3)
y=ae^(-bx)
Graph showing % Wt.Loss Vs % Fly Ash Replacement in Higher Grades
% Wt.Loss
% Fly ash Replacement
Exp
Theo
a=4.144
b=10.38*10^(-3)
y=ae^(-bx)

Figure 3.

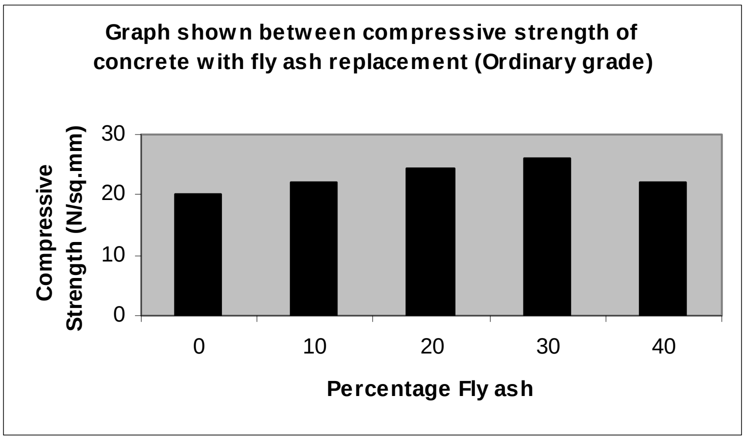


Figure 4.

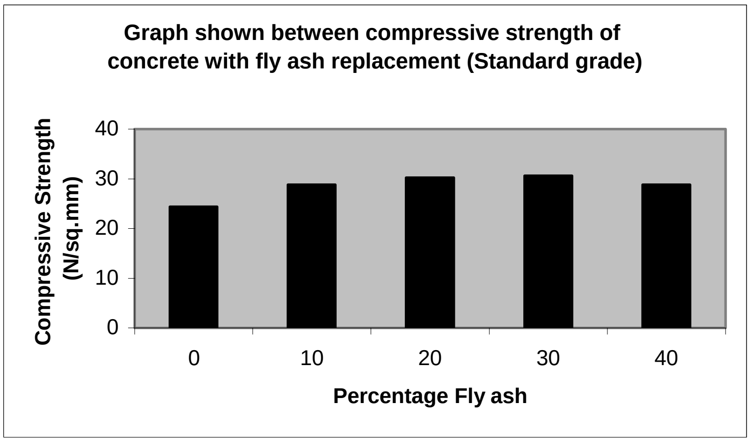


Figure 5.

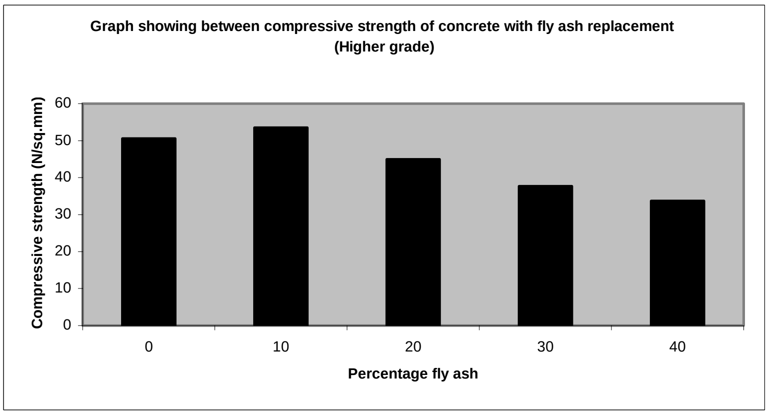


Figure 6.

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