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RELIABILITY ANALYSIS ON PROPERTIES OF FLY ASH CONCRETE FOR THE DETERMINATION OF COMPRESSIVE STRENGTH

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ABSTRACT

Concrete is the most important engineering material in construction industry because of its inherent strength properties. However, the addition of some other materials may change the properties of concrete. With increase in trend towards the wider use of concrete for pre-stressed concrete and high rise buildings there is a growing demand of concrete with higher compressive strength. The mineral admixtures with pozzolanic properties such as fly ash, silica fume, ground blast-furnace slag and metakaolin are commonly used as a partial substitution of Portland cement during construction. An experiment is carried out to examine the effects of Fly Ash on compressive strength of concrete for different quantity of Fly Ash, taking into account different curing periods. An investigation has also been conducted to examine the effects of Fly Ash on mechanical properties of concrete by mixing of concrete with varying percentage of Fly Ash. The compressive strength of concrete was measured by 7,14 and 28 days and the compaction factor was taken from the measurement of workability. By replacing different proportions of cement with Fly Ash, the compressive strength of cement has been checked and the results have been found effective and applicable. In this study, the effects of Fly Ash as partial replacement of cement in concrete and to ascertain the use of optimum quantity of Fly Ash for different qualities of concrete which will be acceptable , applicable and economical. Here it is also explained the variation in compressive strength of different qualities of concrete at different percentage of Fly Ash at various curing periods. In this study, the results of the structural reliability analysis will be used to find an optimum set of values for the target mean and standard deviation of the concrete compressive strength to be produced at the lowest cost. The required compressive concrete strength can be more accurately determined if the production facility's coefficient of variation of the compressive strength, the type of the structural element for which the concrete. Hence, the present investigation provides a practical platform to efficiently consider these factors in the mix design process. In the present study, Reliability based partial safety factors for compressive strength of concrete with partial replacement of cement by fly ash has been developed considering the strength as a random variable.

Keywords: FLY-ASH, PROBABILISTIC ANALYSIS, RELIABILITY INDEX, CHI-SQUARE.

1. INTRODUCTION

Concrete is an artificial material in which the aggregates both fine and coarse are bounded together by the cement when mixed with water. Its great versatility and relative economy in filling wide range of needs has made it a very competitive building material. The compressive strength of concrete in turn depends upon the properties of its constituent materials viz, cement, fine aggregates, coarse aggregates, fly ash etc. The most important pozzolanic materials are flyash, silica fume, and meta kaolin whose use in cement and concrete is likely to be a significant achievement in the development of the concrete technology in the coming few decade.

The use of pozzolanic materials in cement concrete paved a solution for

i. Modifying the properties of the concrete.
ii. Controlling the production cost of concrete.
iii. To overcome the scarcity of cement.
iv. The economic disposal of industrial wastes.

Flyash, an artificial Pozzolona, is the unburnt residue resulting from combustion of pulverized coal or lignite, mechanical or electrostatic separators called hoppers collect it from flue gases of power plants where powdered coal is used as fuel.

1.2 FLY ASH

There are two basic types of fly ash: Class F and Class C. Both types react in concrete in similar ways. Both Class F and Class C fly ashes undergo a pozzolanic reaction with the lime (calcium hydroxide) created by the hydration (chemical reaction) of cement and water, to create the same binder (calcium silicate hydrate) as cement. In addition, some Class C fly ashes may possess enough lime to be self-cementing, in addition to the pozzolanic reaction with lime from cement hydration

1.3 Effect of flyash on performane of concrete :

Flyash has standards in many countries. Use of right quality fly ash, results in reduction of water demand for desired slump. With the reduction of unit water content, bleeding and drying shrinkage will also be reduced. Since fly ash is not highly reactive, the heat of hydration can be reduced through replacement of part of the cement with fly ash. Fly ash, when used in concrete, contributes to the strength of concrete due to its pozzolanic reactivity. The pozzolanic reaction also contributes to making the texture of concrete dense, resulting in decrease of water permeability & gas permeability. It should be noted that since pozzolanic reaction can only proceed in the presence of water, fly ash concrete should be cured for longer time. Dams will derive full benefits of attaining improved long term strength and water tightness.

1.4 Advantages of flyash :

Some of the benefits of flyash in concrete over the corresponding plain cement concrete are

1. Improved workability
2. Low heat of hydration
3. Reduced bleeding
4. Low water and air permeability
5. Superior resistance to freezing and thawing
6. Improved sulphate resistance
7. Lowered costs

2. METHODOLOGY

2.1 Procedure for basic Material tests :

Step 1: Specific gravity and water Moisture Content test for Fine Aggregates.

Step 2: Sieve Analysis for Fine Aggregates.

Step 3: Specific gravity and Water Absorption of Coarse Aggregates.

Step 4: Specific Gravity of Cement.

Step 5: Specific Gravity of Flyash.

2.2 Mix Design Calculation for M25 grade of concrete as per IS10262:2009

1. Trial number 1: Nominal concrete (Cement: 100% and Flyash: 0%)
2. Trial number 2: Partial replacement of flyash (10%) with Cement (90%)
3. Trial number 3: Partial replacement of flyash (20%) with Cement (80%)
4. Trial number 4: Partial replacement of flyash (30%) with Cement (70%)
5. Trial number 5: Partial replacement of flyash (40%) with Cement (60%)
6. Trial number 6: Partial replacement of flyash (50%) with Cement (50%)

2.3 Determination of Partial safety factor

- Collection and Statistical analysis of the data on basic variable (Compressive Strength).
- Determination of the probability distribution of each variable of mean, standard deviation and coefficient of variation.
- Evaluation of the partial safety factor.

2.4 Normal Distribution :

Normal distributions has the constants μ and $\sigma > 0$ are arbitrary and represent the mean and standard deviation of a random variable.

This is the most important probability distribution for use in statistics.

The mean is calculated as (ACI 214R-11)

Mean, $\mu = \frac{Sum\ of\ samples}{Total\ no.of\ samples}$

The sample standard deviation is calculated as (ACI 214R-11)

Standard deviation, $\sigma = \sqrt{\frac{\sum(x-\mu)^2}{n-1}}$

The coefficient of variation V_R, is used to describe the degree of dispersion relative to the mean and is calculated as (ACI 214R-11)

Co-efficient of variation, COV or $V_R = \frac{\sigma}{\mu}$ x 100

2.5 Chi-square Test

A chi-squared test (also chi-square or χ^2 test) is a statistical hypothesis test used in the analysis of contingency tables when the sample sizes are large. In simpler terms, this test is primarily used to examine whether two categorical variables (*two dimensions of the contingency table*) are independent in influencing the test statistic (*values within the table*).

Finding P-Value

P stands for probability here. To calculate the p-value, the chi-square test is used in statistics. The different values of p indicate the different hypothesis interpretation, are given below:

- P≤ 0.05; Hypothesis rejected
- P>.05; Hypothesis Accepted

Probability is all about chance or risk or uncertainty. It is the possibility of the outcome of the sample or the occurrence of an event.

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Properties

The following are the important properties of the chi-square test:

- ✓ Two times the number of degrees of freedom is equal to the variance.
- ✓ The number of degrees of freedom is equal to the mean distribution
- ✓ The chi-square distribution curve approaches the normal distribution when the degree of freedom increases.

The chi-squared test is done to check if there is any difference between the observed value and expected value.

The formula for chi-square can be written as

$$\chi^2 = \Sigma \frac{(o_i - e_i)^2}{e_i}$$

Where, χ^2 = Chi-square Test

o_i = $Observed\ value$

e_i = $Expected\ value$

Degree of freedom = n-1

Here, n is a number of samples

3. RESULTS & DISCUSSION

The material test are obtained and the results are given by

Table 1: Physical properties of cement

SL.NO.	Property	Value
1	Fineness of cement	4.52 %
2	Specific gravity	3.14
3	Normal consistency	33
4	Setting time i. Initial setting time ii. Final setting time	 40 minutes 6 hours

Table 2: Properties of Fine aggregate

SL.NO.	Property	Value
1	Specific gravity	2.65
2	Fineness Modulus	3.65
3	Water Absorption	2.0%
4	Free Moisture Content	0.001%

Table 3: Properties of Coarse aggregate

SL.NO.	Property	Value
1	Specific Gravity	2.80
2	Water absorption	0.28%
3	Impact Value	15.60%

3.1 Compressive Strength calculations for proportions of Flyash

Size of the cube 150mmx150mmx150mm for each mix

Compessive Strength = $\frac{Load}{Area}$

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Table 4: Cube Compressive strength at 7,14 and 28 Days in N/mm^2

Percentage of Flyash	7 Days N/mm^2	14 Days N/mm^2	28 Days N/mm^2
0%	22.37	25.53	31.08
10%	22.73	24.02	27.02
20%	23.51	26.14	28.51
30%	20.28	22.14	24.58
40%	17.82	19.19	21.29
50%	15.71	17.92	17.24

Table 5: Compressive Strength parameters for different concrete mixes

Percentage of Flyash	7 Days of Curing			14 Days of Curing			28 Days of Curing		
	Mean Mpa	SD Mpa	CoV Percent	Mean Mpa	SD Mpa	CoV Percent	Mean Mpa	SD Mpa	CoV Percent
0%	22.37	0.69	3.08	25.53	0.87	3.40	31.08	1.76	5.66
10%	22.73	0.80	3.52	24.02	0.75	3.12	27.02	1.71	6.32
20%	23.51	1.20	5.10	26.14	0.66	2.52	28.51	0.36	1.26
30%	20.28	0.60	2.97	22.14	1.52	6.86	24.58	0.89	3.62
40%	17.82	1.64	9.20	19.19	1.75	9.15	21.29	2.08	9.7
50%	15.71	0.86	5.47	17.92	0.71	3.96	17.24	0.75	4.35

3.2 Partial Safety Factor

- Partial safety factor with respect to the characteristic value or the characteristic strength of concrete (the value of the strength of 150mm cubes, after 28 days of curing below which not more than 5 per cent of the test results are expected to fall) is defined as :

$$\gamma_m = \frac{f_d}{\mathrm{f}}$$

Where,

γ_m = Partial safety factor

f = characteristic strength of the material

f_d = Design value

Table 6: Partial Safety Factor (PSF) for concrete with 0%, 10%, 20%, 30%, 40%, 50%

Percentage of Flyash	7 Days of Curing	14 Days of Curing	28 Days of Curing
0%	1.05	1.05	1.10
10%	1.06	1.05	1.09
20%	1.08	1.04	1.16
30%	1.05	1.10	1.08
40%	1.15	1.13	1.06
50%	1.06	1.06	1.02

Table 4: Margin of Safety

A safety margin "g" is also known as the perform function is defined as the difference between the resistance of a structural component and the load effect it is subjected to and is given by

$$g = R - S$$

Where, R and L are treated as random variables and g is also a random variable.

The distribution of g is used to find the probability of failure of the component.

Table 7: Margin of safety

Percentage of Flyash	7 Days of Curing	14 Days of Curing	28 Days of Curing
0%	1.13	1.14	2.90
10%	1.32	1.23	2.83
20%	1.98	1.09	2.59
30%	0.99	2.50	1.48
40%	2.70	2.90	1.43
50%	0.94	1.17	1.23

4. Reliability Prediction

4.1 Chi-square test:

The chi-square test is used to estimate how likely the observations that are made would be, by considering the assumption of the null hypothesis as true.

A hypothesis is a consideration that a given condition or statement might be true, which we can test afterwards. Chi-squared tests are usually created from a sum of squared falsities or errors over the sample variance.

Finding P-Value

P stands for probability here. To calculate the p-value, the chi-square test is used in statistics. The different values of p indicate the different hypothesis interpretation, are given below:

- $P \leq 0.05$; Hypothesis rejected
- P>.05; Hypothesis Accepted

Probability is all about chance or risk or uncertainty. It is the possibility of the outcome of the sample or the occurrence of an event. But when we talk about statistics, it is more about how we handle various data using different techniques. It helps to represent complicated data or bulk data in a very easy and understandable way. It describes the collection, analysis, interpretation, presentation, and organization of data. The concept of both probability and statistics is related to the chi-squared test.

Table 8: The statistical analysis used in compressive strength for 28 Days of Curing

Proportions	Compressive Strength for 28 Days			Hypothesis Test	p-value
	Mean Mpa	SD Mpa	CoV Percent		
0%	31.08	1.76	5.66	χ^2	0.90
10%	27.02	1.71	6.32	χ^2	0.75
20%	28.51	0.36	1.26	χ^2	0.72
30%	24.58	0.89	3.62	χ^2	0.65
40%	21.29	2.08	9.7	χ^2	0.04

50%	17.24	0.75	4.35	χ^2	0.02

When strength exceeds stress, difference between strength and stress will be zero. Thus, we need to find probability that this difference is greater than zero. This can be done by calculating Z-score are :

Percentage of Flyash	7 Days N/mm^2	14 Days N/mm^2	28 Days N/mm^2
0%	1.42	1.43	1.44
10%	1.43	1.43	1.42
20%	1.42	1.44	1.44
30%	1.43	1.43	1.43
40%	1.43	1.43	1.42
50%	1.03	1.42	1.42

According to Standard Normal Distribution Table, the Z-values are used in probability of success and probability of failure

Percentage of Flyash	7 Days N/mm^2		14 Days N/mm^2		28 Days N/mm^2	
	p_f	p_s	p_f	p_s	p_f	p_s
0%	0.0778	0.9222	0.0768	0.9232	0.0749	0.9251
10%	0.0768	0.9232	0.0768	0.9232	0.0778	0.9222
20%	0.0778	0.9222	0.0749	0.9251	0.0749	0.9251
30%	0.0768	0.9232	0.0768	0.9232	0.0768	0.9232
40%	0.0778	0.0922	0.0768	0.9232	0.0778	0.9222
50%	0.1515	0.8485	0.0749	0.9222	0.0778	0.9222

5. COST ANALYSIS

Cost of concrete is depending upon the quantity, quality and proportion of materials used. As M25 Grade concrete is high grade concrete, use of cement is more to achieve early high strength. Replacement of cement by other material not only changes the strength properties of cement but also changes the cost of that particular design.

List of material used for trials and their respective cost as per market value is given below:-

1. Cement (brand Jaypee Cement) – 350 Rs per 50kg bag (i.e. 1kg = 7lit).
2. Fly ash of F-grade – 1000Rs per Ton (i.e. 1kg = 1Rs).
3. Crush Sand – 1 brass = 2205Rs (i.e. 0.3rs/kg).
4. 10 mm aggregate – 1 brass = 1572Rs (i.e. 0.202rs/kg).
5. 20 mm aggregate – 1 brass = 1572Rs (i.e. 0.202rs/kg).

Estimating of each trial for 1m^3 concrete is done by taking above cost of each material multiplied to the quantity used in it. Total estimation of each trial mix proportion will give exact differences of cost at the time of replacement.

Table 11. ***Estimation cost of each trial carried in Trial Mix Design***

Material	0%	10%	20%	30%	40%	50%
Cement	3,850	3,465	3080	2,695	2,310	1,925

Flyash	0	55.44	110.88	166.32	221.76	277.2
C-sand	165.3	165.3	165.3	165.3	165.3	165.3
10mm	64.13	64.13	64.13	64.13	64.13	64.13
20mm	192.40	192.40	192.40	192.40	192.40	192.40
Total Cost	4,271.83	3,942.27	3,612.71	3,283.15	2,953.59	2,624.03

6. CONCLUSION

1. The compressive strength of concrete mixes decrease with increase presence of Fly Ash. It should be kept in mind that the optimum limit of mixing of Fly Ash is 20 % and more than that may not be safe for different concrete mixes.
2. Generally with the increase of fly ash there is steep increase in strength from 7 to 28 days which is indicative that early strength of concrete is reduced with increase in proportion of fly ash.
3. Depending upon the percentage of Fly Ash as well as time of curing sometimes mixes of higher strength can be economical than that of mix of lower strength.
4. Concrete mixes with Fly ash provide higher partial safety factors. Partial safety factors vary exponentially with increase in reliability index.
5. The partial safety factors computed can be used in design of elements using concrete with flyash.
6. The partial replacement of cement by pozzolanic material (20% of flyash) is most optimum replacement, enhancing the compressive strength.
7. Addition of flyash partially replacing cement in concrete mix results in achieving economy as well as reducing green gas emission.

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