

# FLY ASH BASED CONCRETE: EXPERIMENTAL AND STATISTICAL ANALYSIS

Souradip Bhattacharjee, Mainak Chatterjee, Pranoy Roy\*, and Sanjay Sengupta

Received: February 05, 2024; Revised: May 14, 2024; Accepted: July 02, 2024

## Abstract

Concrete is considered a durable and strong material. Concrete is an admired material in construction and is consumed in high volume in India as well as globally. Fly ash being a by-product of coal burning is also produced in high quantities from the steel and thermal power sector of India. This research is based on utilizing the waste material in concrete as a restricted substitution of cement, finding a suitable mix that shows healthy mechanical properties for strength, durability, and workability, and validating test results with ANOVA statistical analysis. Low strength M20 and M25 concrete mixes were designed as per IS10262-2019 code guidelines and treated as a base mix. Cement was substituted with varying percentages of fly ash, ranging from 10% to 30%. These mixes were tested for compression and tension by casting 90 samples of cubes and cylinders of standard sizes and further testing. Test results suggest that restricted substitution of cement by Fly ash up to 20% shows a positive response. ANOVA test results were in line with the experimental data.

**Keywords:** ANOVA; Cement Replacement; Durability; Fly ash; Mechanical Properties; Statistical Analysis

## Introduction

The construction industry plays a major role in developing nations and the government spends a huge amount on building the nation like bridges, buildings, dams, etc. The approximate requirement of concrete is 12 billion tons every year. At present, 4,100,000 thousand metric tons of cement are produced every year, which constitutes nearly 5% of the total human-made emissions that lead to global warming (Singh *et al.*, 2017). In the Indian scenario, the consumption of cement has increased by 64.78%

in the past decade from 230 million metric tons (2012) to 379 million metric tons (2022) and will further increase in decades to come (Central Electricity Authority, 2021). The trend of usage is shown in Figure 1.

Therefore, the utilization of Portland Pozzolana Cement (PPC), which consists of 30% fly ash, can offer a possible solution to reducing the use of cement and the cost of concrete.

---

Department of Civil Engineering, DR. B.C. Roy Engineering College, Durgapur, West Bengal, India. E-mail: souradip188@gmail.com; emailtomainak@gmail.com; pranoyroy.dgp@gmail.com; sanjay.sengupta@bcrec.ac.in

\* Corresponding author

DOI: <https://doi.org/10.55766/sujst-2024-04-e03499>

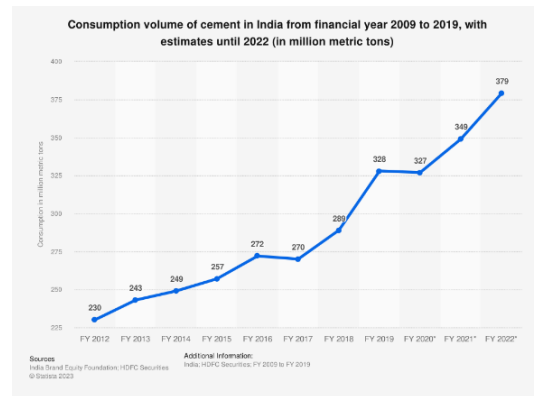
Suranaree J. Sci. Technol. 31(4):010317(1-9)

The majority of fly ash is generated in India by the thermal power plants and steel manufacturing industries. Reports by the Ministry of Power Government of India suggest that 4.05% of fly ash remains unutilized as shown in Figure 2, where the fly ash generation is also increasing rapidly year by year as shown in Figure 3.

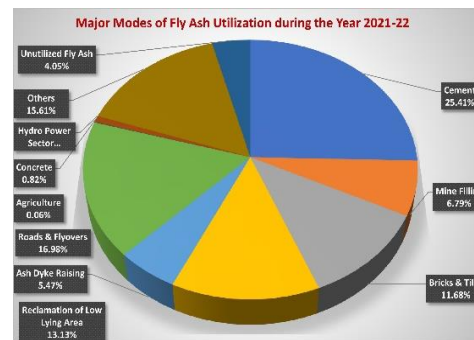
Several studies were conducted on the use of pozzolanic waste in concrete reducing energy demand and waste reduction and have shown the ingress of fly ash (Balasubramanian *et al.* 1996; Kondraivendhan and Bhattacharjee 2015; Tarangini *et al.*, 2021). With the increased demand for concrete, sustainable construction practices are essential to maintain the ecological balance. The use of waste materials in construction helps to reduce the solid waste generated as well as the cost of concrete is reduced to a certain extent.

Reduction in water requirement and lower heat of hydration and lower initial strength gain (Ganesan *et al.*, 2007), whereas reduced tensile strength of concrete was reported by Kou *et al.* (2007) and Ghosh *et al.* (2011) studied the microstructure and mineralogical changes fly ash based geopolymer concrete (Okoye *et al.*, 2015; Jeevanandan and Sreevidya 2020; Rameshwaran and Madhavi 2020). Statistical analysis of fly ash based concrete by Poojari and Kampilla (2020) highlighted the significant influence of fly ash on the durability of concrete and 10% replacement of cement showcased positive results.

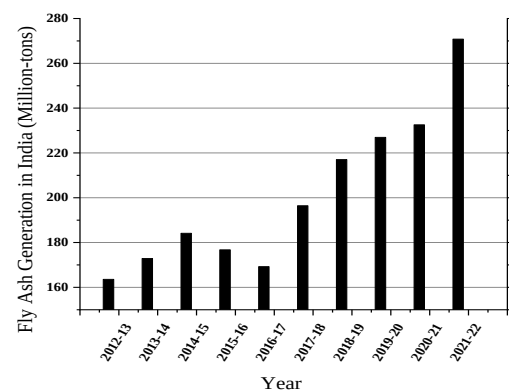
Ramachandran *et al.* examined higher strength (Fantu *et al.* 2021) and durability properties of superplasticizer based fly ash concrete in saline environments. (Uthaman *et al.*, 2018b). Improvement in pore structure and density of concrete with the presence of nano-fillers with fly ash increases the durability (Nath and Sarker 2011; Shaikh and Supit 2014; Uthaman *et al.* 2018a). The leaching of fly ash was observed by (Ahmaruzzaman 2010), when the fly ash based concrete was exposed to water, causing the reduction in top cover and polluting water. Nanophase modification enhanced the pozzolanic behaviour of the fly ash concrete resulting in faster hydration, higher initial strength, carbonation (Hussain *et al.*, 2017) depth, and internal pH (Uthaman *et al.* 2018a) which makes the concrete suitable for all weather applications. Natural rubber latex (NRL) concrete improved the flexural and compressive strength of concrete meeting the codal requirements with the reduction in the cost of construction (Yaowarat *et al.*, 2021). The fatigue cracking failure of concrete was restricted by NRL with improved mechanical properties (Apichat *et al.* 2022; Samingthong *et al.* 2023) found that PET and crumb rubber aggregate replacing aggregates



**Figure 1. Consumption of cement in India in metric tons. 2012-2022 (Central Electricity Authority, 2021)**



**Figure 2. Flyash utilization in India for the year 2021-2022 (Central Electricity Authority, 2021)**



**Figure 3. Flyash Generation in India in Million Tons from 2012-2022 (Central Electricity Authority, 2021)**

improves the energy absorption of concrete with improved ductility.

One way ANOVA statistical test was used by (Raza *et al.*, 2020) to predict the usage of waste

water from industries including textile, fertilizer, sewerage, service station, and a sugar factory in concrete and its durability properties. The mechanical behavior of concrete (Varadharajan, 2020) with recycled aggregates and fly ash was studied by (Vairagade *et al.*, 2021) using numerical analysis using the way ANOVA model and the Shapiro-Wilks test to provide optimized solutions.

Based on the literature study and the identified gaps the fly ash is replaced with cement at an increasing percentage of 10% and tests were carried out with the replacement percentage of 10%, 20%, 30% and 40%. Previous studies indicate that beyond 40% the the replacement shows reduced values for the mechanical behaviour of the concrete (Poojari and Kampilla 2020; Fantu *et al.* 2021; Kumar and Kumar 2022).

Hence the attempt is made through this study to find a suitable mix of cement and fly ash as the binder that shows healthy mechanical properties for strength, durability and workability and can be recommended in construction. Finally, the ANOVA statistical test validated the results for a significance of 5 percent.

#### Highlights of the Study:

- Study the mechanical behaviour of low-strength concrete M20 and M25 with fly ash replacing cement up to 40%.
- To validate the experimental results with the statistical data Interpretation.
- This study aims to address the requirements of low-cost housing (Ministry of Housing and Urban Affairs, Government of India, 2022) minimizing the cost of concrete in construction.
- Replacement of cement with fly ash in concrete in appropriate dosage will reduce the cost of concrete production, which will add up to the lost cost of housing for all citizens of India.
- The novelty of this study is aimed to replace the temporary roofed houses by low cost concrete slabs, which will increase the longibility of

the houses and the roofs will not blow away by the wind.

Determining the mechanical parameters of concrete with substitution of cement by different percentages of fly ash as 10%, 20%, 30%, and 40%.

To compare the significance of results using a way ANOVA statistical testing tool.

## Materials and Methodology

### Materials

Portland Slag Cement 53 grade conforming to IS456-2016 nuvoco concreto cement was used for this study. The physical properties of cement are given in Table 1.

Class-F fly-ash from the Mejia Thermal Power Station, India, has been used for the present research. The physical and chemical properties are given in Table 2.

Natural river sand of Zone-2 as per IS-383 (Bureau of Indian Standards, 1970) (Table 3) was

**Table 1. Physical properties of cement**

| Properties             | Range |
|------------------------|-------|
| Normal consistency (%) | 30    |
| Specific gravity       | 3.1   |
| Fineness (%)           | 5     |

**Table 2. Physical and chemical properties of fly ash**

| Chemical composition                                                             | Value<br>(% by mass) |
|----------------------------------------------------------------------------------|----------------------|
| SiO <sub>2</sub> +Al <sub>2</sub> O <sub>3</sub> +Fe <sub>2</sub> O <sub>3</sub> | 88                   |
| SiO <sub>2</sub>                                                                 | 56.2                 |
| CaO                                                                              | 2.4                  |
| MgO                                                                              | 1.3                  |
| Na <sub>2</sub> O                                                                | 0.4                  |
| Total Chlorides, Cl                                                              | 0.06                 |
| Sulphur Trioxide (SO <sub>3</sub> )                                              | <0.02                |
| Loss on Ignition                                                                 | 1.9                  |
| Physical properties                                                              | Test value           |
| Fineness, m <sup>2</sup> /kg                                                     | 330                  |
| Soundness, %                                                                     | 0.04                 |
| Specific gravity                                                                 | 2.9                  |

**Table 3. Mix proportion of specimens (by weight)**

| Sample ID  | Cement | Flyash | Fine aggregate | Coarse Aggregate |
|------------|--------|--------|----------------|------------------|
| S20C100-F0 | 1.00   | 0      | 1.50           | 3.00             |
| S20C90-F10 | 1.00   | 0.1    | 1.67           | 3.34             |
| S20C80-F20 | 1.00   | 0.2    | 1.88           | 3.75             |
| S20C70-F30 | 1.00   | 0.3    | 2.01           | 4.01             |
| S20C60-F40 | 1.00   | 0.4    | 2.14           | 4.28             |
| S25C100-F0 | 1.00   | 0      | 1.00           | 2.00             |
| S25C90-F10 | 1.00   | 0.1    | 1.11           | 2.22             |
| S25C80-F20 | 1.00   | 0.2    | 1.25           | 2.50             |
| S25C70-F30 | 1.00   | 0.3    | 1.34           | 2.67             |
| S25C60-F40 | 1.00   | 0.4    | 1.43           | 2.85             |

used in this investigation, and angular crushed natural aggregates with a size restricted to 20 mm is used. The physical properties are given in Table 4. Normal water having a pH value of 7 was used for mixing and curing of specimens.

### Mix Proportion

Two mixes of grade M20 and M25 were designed using IS-10262-2019 (Bureau of Indian Standards, 2009) for casting ninety-five specimens, with a water cement ratio of 0.45 based on recommendations of IS-456 (Table 5) (Bureau of Indian Standards, 2000) for 20 mm coarse aggregates, as given in Table 4 with the different sample quantities by weight as per IS-10262 codal recommendations. The base mix was designed with no fly ash replacing cement and the other four mix with 10, 20, 30 and 40% replacement of cement by fly ash. Cubes of size 150×150×150 mm for compressive strength, cylinders of size 150×300 mm for split tensile. Cubes and cylinders were tested for 7 and 28 day strength. This study uses the mean of three samples in each case with a total of 60 cubes and 30 cylinders were tested after casting and curing. Figure 4 shows the different samples and the test arrangement used in this study.

### Methodology

Concrete cubes were cast of size 15×15×15 cm and cured for 7 days and 28 days and then tested for uniaxial compression in compression testing machine CTM at a rate of 140 kg/sqcm/min as per IS-516 (Bureau of Indian Standards, 1959) recommendations. Split tensile tests were conducted on 30×15 cm cylinders by loading them in CTM in

**Table 4. Physical properties of aggregates**

| Properties       | Fine aggregate | Coarse aggregate |
|------------------|----------------|------------------|
| Size range (mm)  | 0.075-4.75     | 10-20            |
| Specific gravity | 2.54           | 2.69             |
| Fineness modulus | 2.95           | 6.84             |
| Porosity         | 42.8           | 40.00            |
| Void ratio       | 0.75           | 0.44             |



**Figure 4. Casting of samples**

horizontal direction as per IS-5816 (Bureau of Indian Standards, 1999). Flexural capacity was conducted on specimens of size 15×15×70 cm by conducting 4 point bending test using flexural testing apparatus as per IS-516. The rate of loading was fixed to 180 kg/min. The flexural strength is indicated in Table 6.

## Results and Discussion

### Workability

Slump cone test determined the workability of the different mixes as shown in Table 5.

**Table 5. Compressive strength of cube and cylinder specimens**

| Sample ID  | Grade | 7 Days Compressive Strength (Mpa) | 28 Days Compressive Strength (Mpa) | Slump in mm <sup>7</sup> |
|------------|-------|-----------------------------------|------------------------------------|--------------------------|
| C20C100-F0 | 20    | 17.87                             | 26.17                              | 112                      |
| C20C90-F10 | 20    | 18.76                             | 28.58                              | 121                      |
| C20C80-F20 | 20    | 18.44                             | 27.66                              | 131                      |
| C20C70-F30 | 20    | 17.63                             | 26.11                              | 119                      |
| C20C60-F40 | 20    | 17.09                             | 24.87                              | 117                      |
| C25C100-F0 | 25    | 21.07                             | 33.41                              | 105                      |
| C25C90-F10 | 25    | 22.57                             | 34.14                              | 114                      |
| C25C80-F20 | 25    | 22.14                             | 35.74                              | 127                      |
| C25C70-F30 | 25    | 21.62                             | 33.14                              | 117                      |
| C25C60-F40 | 25    | 20.84                             | 32.79                              | 109                      |
| S20C100-F0 | 20    | -                                 | 17.21                              | 112                      |
| S20C90-F10 | 20    | -                                 | 18.75                              | 121                      |
| S20C80-F20 | 20    | -                                 | 18.15                              | 131                      |
| S20C70-F30 | 20    | -                                 | 17.52                              | 119                      |
| S20C60-F40 | 20    | -                                 | 15.59                              | 117                      |
| S25C100-F0 | 25    | -                                 | 22.18                              | 105                      |
| S25C90-F10 | 25    | -                                 | 22.86                              | 114                      |
| S25C80-F20 | 25    | -                                 | 23.16                              | 127                      |
| S25C70-F30 | 25    | -                                 | 22.59                              | 117                      |

**Table 6. Compressive strength of cube and cylinder specimens**

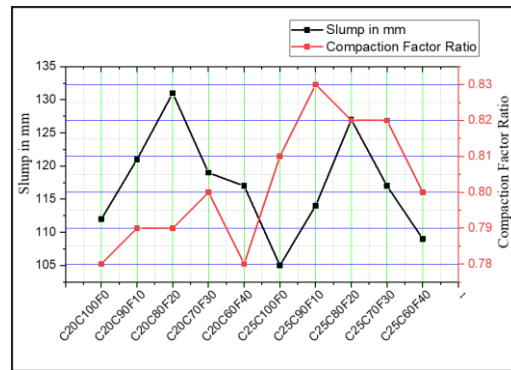
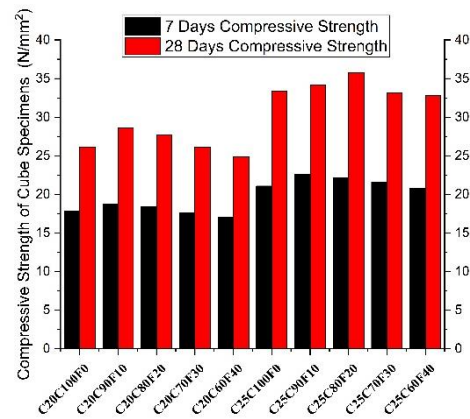
| Sample ID  | Grade | 28 Days Split Tensile Strength (Mpa) | 28 Days Flexural Strength (Mpa) | Compaction Factor Value |
|------------|-------|--------------------------------------|---------------------------------|-------------------------|
| S20C100-F0 | 20    | 1.87                                 | 3.59                            | 0.78                    |
| S20C90-F10 | 20    | 2.14                                 | 3.84                            | 0.79                    |
| S20C80-F20 | 20    | 2.07                                 | 3.72                            | 0.79                    |
| S20C70-F30 | 20    | 1.81                                 | 3.58                            | 0.8                     |
| S20C60-F40 | 20    | 1.45                                 | 3.48                            | 0.78                    |
| S25C100-F0 | 25    | 2.39                                 | 4.01                            | 0.81                    |
| S25C90-F10 | 25    | 2.47                                 | 4.09                            | 0.83                    |
| S25C80-F20 | 25    | 2.87                                 | 4.18                            | 0.82                    |
| S25C70-F30 | 25    | 2.21                                 | 4.04                            | 0.82                    |
| S25C60-F40 | 25    | 2.11                                 | 4.03                            | 0.8                     |

The workability increased with the replacement of 10% with a peak at 20% mainly due to throughout gradation of the aggregates where the size of aggregate is divided homogeneously across all sizes and acts as tiny spheres in the mix, providing a lubricating effect (Ge *et al.*, 2023). Further replacement causes reduced workability with 30% and 40% replacement of cement. The formation of lumps was observed with a higher dosage of fly ash. The range of workability lay in the range of 109-131mm for the different mix types which shows a similar pattern to the results obtained by (Fantu *et al.*, 2021) with a slump range of 45-85 mm for high strength concrete.

The compaction factor test was performed per IS-1199 (Bureau of Indian Standards, 1959). The range of compaction as indicated in Table 6 lies in the range of 0.78 to 0.83, which highlights adequate compaction of the concrete, with minimalistic effect of fly ash. The results of the compaction factor test are in line with the results obtained in the range of (0.86-0.92) (Poojari and Kampilla, 2020). The interrelation of results obtained by both tests is shown in Figure 5, which shows the graph pattern in the results for the mix types.

### Compressive Strength

The compressive strength of the cube specimens after a curing of 7 days and 28 days is shown in Table 5 and illustrated in Figure 6. Results showcase that the compressive behaviour of specimens is identical for 7 day and 28 day strength. Replacement of 10% and 20% cement with fly ash enhances the compressive strength of concrete. The decrease in strength in further addition of cement is observed with reduced workability mainly due to the formation of fly ash lumps with water droplets. Detailed observations from Figure 7 show that compressive strength is maximum at 20% replacement of cement for M25 grades of concrete and 10% for M20 grade concrete, indicating that

**Figure 5. Slump and Compaction Factor test results for all concrete mix****Figure 6. Compressive strength of cubes at 7 days and 28 days of curing**

with higher grade of concrete more quantity of cement may replaced with fly ash.

Figure 6 shows a 5% increase in cube specimens of M20 grade for 7 days strength and a 9.2% increase in strength for 28 days whereas in the case of M25 grade specimens, the 7 days increment is 5.07%, whereas 28 days strength gain is 7% when compared with base specimens with no fly ash.

The failure of the specimens is shown in Figure 8 where Figure 8(a) is of specimen id C20C90-F10 made with 10% replaced fly ash, whereas Figure 8(b) is of sample id C20C70-F30 made with 10% replaced fly ash. The figures show that with 30% replaced fly ash, the cube failed with large chunks of concrete crushing and falling, whereas with a lower dosage of fly ash, concrete bursting was not seen. Similarly Figures 8(c) and 8(d) show the failure of cylinder samples under compressive action. With the increase in fly ash content, crushing of concrete was observed before complete collapse.

The compressive strength of cylinders for 28 days curing highlighted in Table 5 and Figure 9

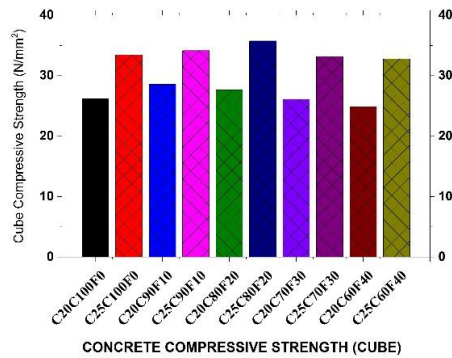


Figure 7. Compressive Strength of Cubes at 28 days



Figure 8. Failure pattern of specimens

showed similar observations where strength was observed for specimens up to 10% fly ash replacement for M20 grade concrete, whereas, for M25 grade, the strength was maximum at 20% replacement. The overall strength of cylinder specimens is in the range of 0.63 to 0.68 as compared to the cube specimens which is lower than the Indian Codal provisions of (0.8 to 0.87, Cube/Cylinder,  $S = \text{strength Ratio}$ ) (Bureau of Indian Standards, 2000).

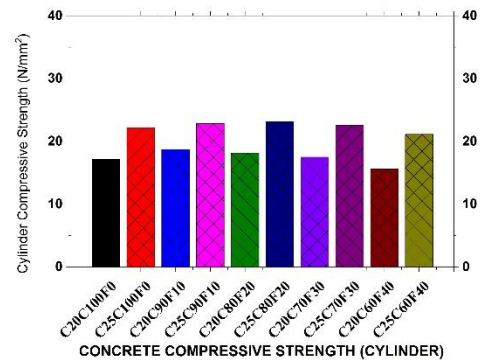


Figure 9. Compressive strength of cylinders at 28 days

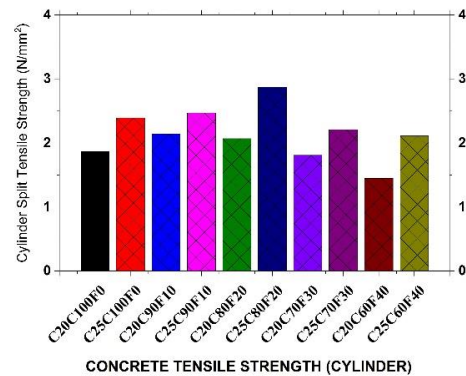


Figure 10. Split Tensile strength of cylinders at 28 days

Table 6. Tensile strength of specimens

| Sample ID  | Grade | 28 Days Split Tensile Strength (Mpa) | 28 Days Flexural Strength (Mpa) | Compaction Factor Value |
|------------|-------|--------------------------------------|---------------------------------|-------------------------|
| S20C100-F0 | 20    | 1.87                                 | 3.59                            | 0.78                    |
| S20C90-F10 | 20    | 2.14                                 | 3.84                            | 0.79                    |
| S20C80-F20 | 20    | 2.07                                 | 3.72                            | 0.79                    |
| S20C70-F30 | 20    | 1.81                                 | 3.58                            | 0.8                     |
| S20C60-F40 | 20    | 1.45                                 | 3.48                            | 0.78                    |
| S25C100-F0 | 25    | 2.39                                 | 4.01                            | 0.81                    |
| S25C90-F10 | 25    | 2.47                                 | 4.09                            | 0.83                    |
| S25C80-F20 | 25    | 2.87                                 | 4.18                            | 0.82                    |
| S25C70-F30 | 25    | 2.21                                 | 4.04                            | 0.82                    |
| S25C60-F40 | 25    | 2.11                                 | 4.03                            | 0.8                     |

### Split Tensile Strength

The split tensile strength of M20 and M25 grade concrete was calculated for 28 days and shown in Table 6 and Figure 10, it is evident that the maximum tensile strength was obtained with a fly ash replacement of 10-20%. Analysis indicates that there is about a 12% increase in the split tensile strength of the fly ash based samples when compared to base specimens. The comparison of split tensile strength to compressive strength the percentage is in a range of (5.83-7.84%) which is lower than the prescribed value of (8-12%) as per Indian Codal Provisions (Bureau of Indian Standards, 2000). Thus it can be concluded that this fly ash replaced concrete is majorly suitable for compression members.

### One Way Analysis of Variation (ANOVA) Test

The results and significance variations were analyzed using the ANOVA statistical test at a 5% significance level. Specimens with 0, 10, 20, 30, and

40% fly ash replacing cement were considered for compressive and Tensile Strength.

In the ANOVA test, when the P-value is greater than 5% in 95% confidence interval, the difference between the results of various concrete mixes is not significant.

The results of the ANOVA test at the 5% significance level for cube and cylinder compressive strength indicated negligible difference between the compressive strengths of various concrete mixes at 28 days of testing ages with a probability of 97.19% and 95.27% and F value lower than the Fcrit value as per Tables 7 and 8. It portrays that the production of concrete with fly ash doesn't affect the compressive strength of concrete significantly and may be used effectively to reduce the overall consumption of cement in concrete.

The results of the ANOVA test at the 5% significance level for cylinder split tensile strength indicated negligible difference between the split tensile strengths of various concrete mixes at

**Table 7. A one-way ANOVA at the 5% significance level for compressive strength of cube specimens**

| Groups         | Count               | Sum                    | Average              | Variance            |
|----------------|---------------------|------------------------|----------------------|---------------------|
| 0%FA           | 2                   | 59.58                  | 29.79                | 26.209              |
| 10%FA          | 2                   | 62.72                  | 31.36                | 15.456              |
| 20%FA          | 2                   | 63.4                   | 31.7                 | 32.642              |
| 30%FA          | 2                   | 59.25                  | 29.625               | 24.71               |
| 40%FA          | 2                   | 57.66                  | 28.83                | 31.363              |
| Variation      | Sum of Squares (SS) | Degree of freedom (df) | Mean of Squares (MS) | F F <sub>crit</sub> |
| Between Groups | 11.905              | 4                      | 2.976                | 0.114 5.192         |
| Within Groups  | 130.382             | 5                      | 26.07649             | P-value             |
| Total          | 142.288             | 9                      |                      | 0.972               |

**Table 8. A One-Way ANOVA at the 5% Significance Level for Compressive Strength of Cylinder Specimens**

| Groups         | Count               | Sum                    | Average              | Variance            |
|----------------|---------------------|------------------------|----------------------|---------------------|
| 0%FA           | 2                   | 39.39                  | 19.695               | 12.35               |
| 10%FA          | 2                   | 41.61                  | 20.805               | 8.446               |
| 20%FA          | 2                   | 41.31                  | 20.655               | 12.55               |
| 30%FA          | 2                   | 40.11                  | 20.055               | 12.852              |
| 40%FA          | 2                   | 36.73                  | 18.365               | 15.401              |
| Variation      | Sum of Squares (SS) | Degree of freedom (df) | Mean of Squares (MS) | F F <sub>crit</sub> |
| Between Groups | 7.620               | 4                      | 1.905                | 0.155 5.192         |
| Within Groups  | 61.601              | 5                      | 12.32                | P-value             |
| Total          | 69.22               | 9                      |                      | 0.953               |

**Table 9. A One-Way ANOVA at the 5% significance level for split tensile strength of cylinder specimens**

| Groups         | Count               | Sum                    | Average              | Variance            |
|----------------|---------------------|------------------------|----------------------|---------------------|
| 0%FA           | 2                   | 4.26                   | 2.13                 | 0.1352              |
| 10%FA          | 2                   | 4.61                   | 2.305                | 0.05445             |
| 20%FA          | 2                   | 4.94                   | 2.47                 | 0.32                |
| 30%FA          | 2                   | 4.02                   | 2.01                 | 0.08                |
| 40%FA          | 2                   | 3.56                   | 1.78                 | 0.2178              |
| Variation      | Sum of Squares (SS) | Degree of freedom (df) | Mean of Squares (MS) | F F <sub>crit</sub> |
| Between Groups | 0.565               | 4                      | 0.141                | 0.875 5.192         |
| Within Groups  | 0.807               | 5                      | 0.161                | P-value             |
| Total          | 1.373               | 9                      |                      | 0.538               |

28 days of testing ages with a probability of 53.84% and an F value lower than the Fcrit value as per Table 9.

ANOVA test results show similar results to experimental observations, which indicates that effective replacement of fly ash gives non-significant changes in results in terms of strength and workability parameters. The overall ANOVA results for the dosage of Fly ash in the mix for all mechanical properties are shown in Figure 11 which shows good agreement with 20% fly ash replacing cement.

However, for flexural members strength loss due to fly ash in concrete is significant and more research needs to be conducted to enhance the strength of concrete with fly ash.

## Conclusions

The results of the laboratory experiments on 90 samples were tested at the concrete laboratory of Dr. B.C. Roy Engineering College highlights the following points:

- The workability increases with 20% replacement of cement by fly ash beyond which lump formation reduces the workability. The slump cone test gives better observations than the compaction factor test in this regard.
- The gain of strength is lower at 7 days compared to 28 days. Replacement by 10% at M20 grade and 20% at M25 grade gives the maximum positive response, indicating that for high strength concrete, the replacement of Fly ash can be higher.
- The effect of fly ash is negligible for tensile strength with insignificant changes.
- The flexural strength of concrete is identical to the compressive behaviour of the concrete. Concrete with 10-20% fly ash shows good results.
- The statistical one way ANOVA test with 5% significance shows similarity with experimental results. Replacement of fly ash by cement up to 20% shows positive mechanical behaviour, further replacement of fly ash beyond 20% reduces the strength significantly.

## Acknowledgement

The authors sincerely acknowledge the support and resources provided by Dr. B.C. Roy Engineering College, India, for supplying the necessary materials and equipment used in this study. Souradip Bhattacharjee was responsible for material collection, casting, testing, and reporting. Mainak Chatterjee contributed to casting, curing,

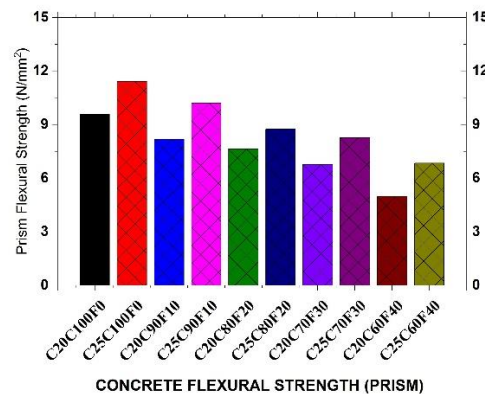


Figure 11. One way ANOVA prediction at 5% significance

testing, and writing. Pranoy Roy was involved in data curation, analysis, mathematical modeling, drafting the original manuscript, and reviewing and editing. Sanjay Sengupta led the conceptualization, methodology, visualization, and investigation, and provided mentoring and review.

## References

- Ahmaruzzaman, M. (2010). A review on the utilization of fly ash. *Progress in Energy and Combustion Science*, 36(3):327-363. <https://doi.org/10.1016/j.pecs.2009.11.003>
- Apichat, S., Apinun, B., Menglim, H., Suksun, H., Thaworn, T., Jitwadee, H., and Arul, A. (2022). Natural rubber latex-modified concrete pavements: Evaluation and design approach. *Journal of Materials in Civil Engineering*, 34(9):4022215. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0004364](https://doi.org/10.1061/(ASCE)MT.1943-5533.0004364)
- Balasubramanian, K., Bharatkumar, B.H., Gopalakrishnan, S., and Parameswaran, V.S. (1996). Impact resistance of steel fibre reinforced concrete. *Indian Concrete Journal*, 70:257-268.
- Bureau of Indian Standards, (BIS). (2009). Concrete mix proportioning - Guidelines. New Delhi: Bureau of Indian Standards.
- Bureau of Indian Standards. (1959). IS-1199: Methods of sampling and analysis of concrete. New Delhi: Bureau of Indian Standards.
- Bureau of Indian Standards. (1959). IS-516: Method of tests for strength of concrete. New Delhi: Bureau of Indian Standards.
- Bureau of Indian Standards. (1970). IS-383: Specification for coarse and fine aggregates from natural sources for concrete. New Delhi: Bureau of Indian Standards.
- Bureau of Indian Standards. (1999). IS-5816: Splitting tensile strength of concrete – Method of test. New Delhi: Bureau of Indian Standards.
- Bureau of Indian Standards. (2000). IS-456: Plain concrete and reinforced concrete. New Delhi: Bureau of Indian Standards.
- Central Electricity Authority, (CEA). (2021). Fly ash generation at coal/lignite based thermal power stations and its utilization in the country. New Delhi.
- Fantu, T., Alemayehu, G., Kebede, G., Abebe, Y., Selvaraj, S. K., and Paramasivam, V. (2021). Experimental investigation

- of compressive strength for fly ash on high strength concrete C-55 grade. *Materials Today: Proceedings*, 46(Part 17):7507-7517. <https://doi.org/10.1016/j.matpr.2021.01.213>
- Ganesan, N., Indira, P.V., and Abraham, R. (2007). Behaviour of steel fibre reinforced high performance concrete members under flexure. *Journal of the Institution of Engineers India Civil Engineering Division*, 88:20-23.
- Ge, W., Wang, A., Zhang, Z., Ge, Y., Chen, Y., Li, W., Jiang, H., Shuai, H., Sun, C., Yao, S., and Qiu, L. (2023). Study on the workability, mechanical property and water absorption of reactive powder concrete. *Case Studies in Construction Materials*, 18:e01777. <https://doi.org/10.1016/j.cscm.2022.e01777>
- Ghosh, S., Ghosh, S., and Aich, A. (2011). Rebuilding C&D waste recycling efforts in India. *Waste Management World*, 12(5).
- Hussain, S., Bhunia, D., and Singh, S.B. (2017). Comparative study of accelerated carbonation of plain cement and fly-ash concrete. *Journal of Building Engineering*, 10:26-31. <https://doi.org/10.1016/j.jobbe.2017.02.001>
- Jeevanandan, K. and Sreevidya, V. (2020). Experimental investigation on concrete and geopolymer concrete. *Materials Today: Proceedings*, 21:307-312. <https://doi.org/10.1016/j.matpr.2019.05.448>
- Kondraivendhan, B. and Bhattacharjee, B. (2015). Flow behavior and strength for fly ash blended cement paste and mortar. *International Journal of Sustainable Built Environment*, 4(2):270-277. <https://doi.org/10.1016/j.ijse.2015.09.001>
- Kou, S.C., Poon, C.S., and Chan, D. (2007). Influence of fly ash as cement replacement on the properties of recycled aggregate concrete. *Journal of Materials in Civil Engineering*, 19(9):709-717.
- Ministry of Housing and Urban Affairs, Government of India. (2022). Discourses on affordable housing in India and best practices under PMAY-U.
- Kumar, B.N. and Kumar, G.V. (2022). Study on combined effects of fly ash, GGBS and advanced nanomaterials on the properties of SCC. *Journal of The Institution of Engineers (India): Series A*, 103(4):1259-1270. <https://doi.org/10.1007/s40030-022-00657-x>
- Nath, P., and Sarker, P. (2011). Effect of fly ash on the durability properties of high strength concrete. *Procedia Engineering*, 14:1149-1156. <https://doi.org/10.1016/j.proeng.2011.07.144>
- Okoye, F.N., Durgaprasad, J., and Singh, N.B. (2015). Mechanical properties of alkali activated fly ash/Kaolin based geopolymer concrete. *Construction and Building Materials*, 98:685-691. <https://doi.org/10.1016/j.conbuildmat.2015.08.009>
- Poojari, Y., and Kampilla, V. (2020). Strength behavior analysis of fiber reinforced fly ash concrete. *Materials Today: Proceedings*, 43:1659-1665. <https://doi.org/10.1016/j.matpr.2020.10.027>
- Rameshwaran, P.M. and Madhavi, T.C. (2020). Flexural behaviour of fly ash based geopolymer concrete. *Materials Today: Proceedings*, 46:3423-3425. <https://doi.org/10.1016/j.matpr.2020.11.755>
- Raza, A., Shah, S.A.R., Kazmi, S.N.H., Ali, R.Q., Akhtar, H., Fakhar, S., Khan, F.N., and Mahmood, A. (2020). Performance evaluation of concrete developed using various types of wastewater: A step towards sustainability. *Construction and Building Materials*, 262:120608. <https://doi.org/10.1016/j.conbuildmat.2020.120608>
- Samingthong, W., Hoy, M., Ro, B., Horpibulsuk, S., Yosthasaen, T., Suddeepong, A., Buritatum, A., Yaowarat, T., and Arulrajah, A. (2023). Natural rubber latex-modified concrete with PET and crumb rubber aggregate replacements for sustainable rigid pavements. *Sustainability (Switzerland)*, 15(19):1-16. <https://doi.org/10.3390/su151914147>
- Shaikh, F.U.A. and Supit, S.W.M. (2014). Mechanical and durability properties of high volume fly ash (HVFA) concrete containing calcium carbonate (CaCO<sub>3</sub>) nanoparticles. *Construction and Building Materials*, 70:309-321.
- Singh, M., Choudhary, K., Srivastava, A., Singh Sangwan, K., and Bhunia, D. (2017). A study on environmental and economic impacts of using waste marble powder in concrete. *Journal of Building Engineering*, 13:87-95. <https://doi.org/10.1016/j.jobbe.2017.07.009>
- Tarangini, D., Abhilash, A., Sravana, P., and Srinivasa Rao, P. (2021). Effect of fly ash on properties of gap graded concrete. *Materials Today: Proceedings*, 51:475-479. <https://doi.org/10.1016/j.matpr.2021.05.582>
- Uthaman, S., Vishwakarma, V., George, R.P., Ramachandran, D., Kumari, K., Preetha, R., Premila, M., Rajaraman, R., and Mudali, U.K. (2018a). Enhancement of strength and durability of fly ash concrete in seawater environments: Synergistic effect of nanoparticles. *Construction and Building Materials*, 187:448-459. <https://doi.org/10.1016/j.conbuildmat.2018.07.214>
- Uthaman, S., Vishwakarma, V., George, R.P., Ramachandran, D., Kumari, K., Preetha, R., Premila, M., Rajaraman, R., Mudali, U.K., and Amarendra, G. (2018b). Enhancement of strength and durability of fly ash concrete in seawater environments: Synergistic effect of nanoparticles. *Construction and Building Materials*, 187:448-459. <https://doi.org/10.1016/j.conbuildmat.2018.07.214>
- Vairagade, V.S., Uparkar, S.S., Lokhande, K.G., Kedar, A.P., Upadhye, S.D., Mungle, N.P., and Professor, A. (2021). A numerical analysis of green sustainable concrete using ANOVA. *Turkish Journal of Computer and Mathematics Education*, 12(6):4605-4612.
- Varadharajan, S. (2020). Determination of mechanical properties and environmental impact due to inclusion of fly ash and marble waste powder in concrete. *Structures*, 25:613-630. <https://doi.org/10.1016/j.istruc.2020.03.040>
- Yaowarat, T., Suddeepong, A., Hoy, M., Horpibulsuk, S., Takaikaew, T., Vichitcholchai, N., and Arulrajah, A. (2021). Improvement of flexural strength of concrete pavements using natural rubber latex. *Construction and Building Materials*, 282:122704. <https://doi.org/10.1016/j.conbuildmat.2021.122704>