# EVALUATING STRENGTH CHARACTERISTICS OF FLY ASH CONCRETE WITH DIFFERENT GRADES OF CONCRETE WITH NATURAL AND RECYCLED AGGREGATE

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**Abstract:**
One of the byproducts produced during the combustion of coal is fly ash. Typically, coal-fired power plant's chimneys capture fly ash. Cement is made with fly ash, which is also sold in local markets as pozzolanic cement. In order to efficiently use flyash and to establish its water sorptivity, experiments are conducted. To quantify sorptivity based on the movement of water in capillaries, experimental research is conducted on three grades of cement concrete with 10, 20, 30, 40, and 50% substitution of cement by flyash with natural and recycled aggregate. Concretes with increasing percentages of fly ash replacement for cement displayed lower cumulative water absorption values, indicating lesser porosity in the cover zone. Utilizing the waste material and lowering $CO_2$ emissions will improve the environment as a result of the increased percentage of cement replacement.

**Keywords:** Compressive Strength, Fly Ash, Recycled aggregate, Split Tensile Strength, Water Sorptivity

## 1. INTRODUCTION

One of the byproducts of burning coal is fly ash. Two types of ash collectively referred to as coal ash is fly ash, which is typically collected from the chimneys of coal-fired power stations; the other type, bottom ash, is recovered from the bottom of coal furnaces. Both silicon dioxide ($SiO_2$), which can be amorphous or crystalline, and calcium oxide (CaO), which is an endemic component of many coal-bearing rock layers, are present at significant levels in fly ash. According to ASTM C618, fly ash is divided into two categories: Class F fly ash and Class C fly ash. The calcium, silica, alumina, and iron composition of the ash determines these classes main distinctions from one another.

In order to assess the durability of cement and fly ash concrete, Gopalan (1996) devised a test to measure the sorptivity of each material. To quantify sorptivity based on water capillary flow, they experimentally cast six grades of fly ash mixtures and three grades of cement concrete. By subjecting the samples to two different curing settings, they evaluated the impact of curing. They noticed that the fly ash concrete's durability attributes were impacted by the curing circumstances. A blend containing 40% fly ash was discovered to lessen the sorptivity by 37% when sufficient curing was offered. It was discovered that sorptivity increased by 60% when the cure was insufficient. It was discovered that the effect of curing on cement concrete was substantially less significant.

Using fine fly ash cement and concrete, Haque and Kayali (1998) explored the characteristics of high strength concrete. Workable high-strength concrete was created using experiments for six combinations. On an equal mass basis, cement was substituted by fine fly ash at 0, 10, and 15%, and the replacement's workability and strength were assessed. The slump was changed from 45 to 110 mm, and the fluid/cementitious ratio was changed from 0.25 to 0.38. Additionally, they looked at the properties of drying shrinkage and water absorption, using them as indicators of durability. The ideal cement replacement rate, according to the authors, is 10%.

The impact of fly ash fineness on the compressive strength, porosity, and pore size distribution of cured cement pastes was experimentally investigated by Prinya et al. in 2005. Class F fly ash, with median particle sizes of 19.1 and 6.4 m, was used to replace Portland cement at 0, 20, and 40% of the weight, respectively. All blended cement paste mixtures employed a water to binder ratio (w/b) of 0.35. The paste's porosity increased but its average pore size dropped when fly ash was used in place of Portland cement. The addition of finer fly ash at all replacement levels resulted in a decrease in the total porosity and capillary pores and an increase in the gel pore.

When fly ash is added to concrete, the reactive silica in the fly ash combines with the calcium hydroxide that is released during cement hydration to generate calcium silicate hydrate gel, according to research by Anurag Misra et al. 2007. They experimented with four ratios of water to cementitious material (cement + fly ash) with a mix ration of 1:1.35:2.03. (0.55, 0.475, 0.40 and 0.340). From 0 to 50% of the cement was substituted with fly ash. For the purpose of evaluating the compressive strength and water absorption tests, they conducted an experimental investigation on twenty-four blends. The findings showed that lower cumulative water absorption and sorptivity values are associated with lower w/cm ratios and larger cement replacement volume.

To enable comparisons between concretes treated with either glass powder or fly ash at the same cement replacement level, Nathan et al. (2008) conducted a thorough analysis. According to strength and hydration studies, 10% is the ideal percentage of glass powder to replace cement in construction projects. Only 5% separates the compressive strengths of amended concretes with fly ash and glass powder at later ages. Blends of glass powder and fly ash that can replace 20% of the cement are effective at limiting expansion. The authors came to the conclusion that adding fine glass powder to concrete may increase its durability.

Glory Joseph et al. (2009) studied fly ash, used to partially substitute cement and also as a replacement for sand in concrete, which affected the material's strength and sorption behaviour. They investigated concrete's microstructure. The authors came to the conclusion that substituting fly ash for sand effectively reduces water absorption and sorptivity caused by the densification of the matrix and matrix-aggregate interfacial connection.

Experimental research on the characteristics of ash concrete that included either hydrated lime or silica fume to increase the early strength of concrete was conducted by Barbhuiya et al. in 2009. Comparing concrete with lime and silica fume to concrete without, the air permeability of the former either reduced or stayed almost the same. They came to the conclusion that silica fume and lime additions also enhanced the sorptivity of concrete.

The properties of fresh concrete, such as unit weight and workability, as well as the hardened concrete's compressive strength, flexural tensile strength, splitting tensile strength, elasticity modulus, sorptivity coefficient, drying shrinkage resistance, and freeze-thaw resistance, were studied by Cengiz and Okan in 2009. On a mass basis, they altered the fly ash concentration between 0 and 30%, and on a volume basis, they varied the fibre volume fraction between 0 and 0.25, 0.5, 1.0, and 1.5%. According to the experimental findings, adding steel fibre to either Portland cement or fly ash concrete increases the sorptivity coefficient while decreasing workability and improving tensile strength qualities.

Charles (2005) conducted experimental research on test cylinders that were made under real-world manufacturing settings using varied amounts of Class C (25-65%) and Class F (25-75%) fly ash and a water-reducing admixture (WRA). The test cylinders were then tested for 7-day compressive strength. The concrete mix containing around 35% Class C or 25% Class F fly ash was found to have the highest seven-day compressive strength for the concrete/fly ash/WRA. But for the production of Class I, II, and III reinforced concrete pipe, substitution ratios of up to 65% Class C or 40% Class F fly ash for cement met or exceeded American Society for Testing and Materials strength criteria.Pastariya et.al (2016) experimental investigated M20 and concluded that 10% of addition of fly ash performed well in both compressive and split tensile strength. Hygrive et.al, (2017) compared the study on the compressive strength of fly ash concretefor both mechanical and durability properties. The authors concluded increase of more amount of fly ash leads to decrease of compressive and split tensile strength.

Ram and Kalidindi (2017) estimated the total amount of construction and demolition waste generated in Chennai using waste generation rates. Saravanakumaret.al (2016), studied the properties of treated recycled aggregates and their impact on the behaviour of concrete strength. Gingaet.al (2020) performed a circular economy on construction anddemolitionwaste as a literature review which discussed the materialrecoveryandproduction. Abreuet.al (2018) evaluated the effect of muti-recycling and evaluated the mechanical performance of coarse aggregate. Kisku et.al (2017) and Chen et.al (2019) performed a critical review and assessed the usage of recycled aggregate as sustainable construction materials. Wang et.al (2021) developed a novel treatment method for recycled aggregate and performed the mechanical properties of recycled aggregate concrete. The majority of concrete strength depends upon the strength of aggregate.Strength and durabilityevaluationofrecycledaggregateconcrete (Yehia et.al, 2015).By adding mineral addition and mixing methods on recycled concrete increases its strength studied by Dilbasand Guneş(2021).

The fly ash is generally used as a part replacement of cement for up to 15 to 30 per cent of cement reduces the strength at ages up to 3 months, but once sufficient calcium hydroxide has been liberated to start the pozzolanic action, the rate of development of strength increases rapidly and equality can be attained after 1 to 3 months. After this stage, the pozzolanic reaction continues at a higher rate than the cement hydration, and higher strength can be obtained. The optimum amount of pozzolana as a replacement may normally range between 10 and 30 percent, but is usually nearer the lower limit and may be as low as 45 to 6 per cent for natural pozzolana. Fine grinding of silica and high temperature curing increase the reactivity of pozzolana. The part replacement results in increased workability, which can be used to reduce water content and, in turn, increase strength thus the water content can be sufficiently reduced to limit the loss at early ages to 25 per cent. As a part replacement of fine aggregate substitution of fly ash for sand as a beneficial effect on the strength even at early ages, but is rather uneconomical. As a simultaneous replacement of cement and fine aggregate replacement enables the strength at a specified age to be equalled depending on the water content.

The recycled aggregate obtained from construction and demolition waste. Just by removing the adhered mortar by rotating in the mixer machine and utilized for the total replacement of aggregate and admixture is added to improve the strength and workability.

## 2. OBJECTIVE

1. To design for M20, M30 and M60 grades of concrete with natural and recycled aggregate.
2. To optimize the percentage of replacement of cement with fly ash with natural and recycled aggregate.
3. To evaluate the mechanical properties of fly ash based concrete.
4. To study the behaviour of water sorptivity.

## 3. MATERIALS

### 3.1 Cement

Ordinary Portland cement (53 grade) available in the local market was used in the investigation. The initial and final settings are testedbased on consistency results. The specific gravity and fineness of cement are tested. Based on the basic material property the compressive strength of cement are tested using cube of 70.6mm at 28 days and their properties are presented in Table 1.

**Table 1 Physical Properties of Cement**

| Sl. No. | Description | Values |
|---|---|---|
| 1 | Consistency | 32% |
| 2 | Initial setting time | 145 minutes |
| 3 | Final setting time | 318 minutes |
| 4 | Specific gravity | 3.15 |
| 5 | Fineness of cement | 4% |
| 6 | Compressive strength at 28 days | 58.92 N/mm$^2$ |

### 3.2 Coarse aggregate

The coarse aggregate available from the local quarry utilized and tested for its various properties and details is tabulated in Table 2by performing a sieve analysis.

**Table 2 Sieve Analysis for Coarse Aggregate**

| Sl. No. | Sieve Size(mm) | Percentage of Passing |
|---|---|---|
| 1 | 40 | 100.00 |
| 2 | 20 | 75.72 |
| 3 | 12.5 | 14.23 |
| 4 | 10 | 1.922 |
| 5 | 4.75 | 0.43 |

| | | |
|---|---|---|
| 6 | Less than 4.75 | 0 |

### 3.3 Recycled aggregate

The recycled aggregate is derived from the construction and demolition waste from the nearby building which is demolished for constructing the apartment. The various properties of coarse and recycled aggregate tests are tabulated in Table 3.

**Table 3 Properties of Coarse and Recycled Aggregate**

| S.No | Description | Coarse Aggregate | Recycled Aggregate |
|---|---|---|---|
| 1 | Specificgravity,$kg/m^3$ | 2.56 | 2.78 |
| 2 | Crushingstrength (%) | 26 | 20 |
| 3 | Waterabsorption(%) | 1.15 | 4.36 |
| 4 | Abrasion(percentageof wear) | 2.50 | 4.05 |

### 3.4 Fine aggregate

The locally available river sand was used as fine aggregate. Sieve analysis is carried out and results are shown in Tables 4 and 5. Zone plays a major role in design of concrete mix.

**Table4 Sieve Analysis of Supplied Fine Aggregate**

| Sl. No. | Sieve Size (mm) | Cumulative Percentage of Passing | Remarks |
|---|---|---|---|
| 1 | 10.0 | 100.00 | The tested sand belongs to Zone – II category. |
| 2 | 4.75 | 84.80 | |
| 3 | 2.36 | 83.10 | |
| 4 | 1.18 | 61.80 | |
| 5 | 0.600 | 39.70 | |
| 6 | 0.300 | 6.40 | |
| 7 | 0.150 | 0.80 | |

**Table 5 Specific Gravity and Bulk Densities of Supplied Fine Aggregate**

| Sl. No. | Fineness Modulus | Specific Gravity | Bulk Density ($Kg/m^3$) | |
|---|---|---|---|---|
| | | | Loose | Rodded |
| 1. | 2.70 | 2.65 | 1651 | 1769 |

### 3.5 Flyash

For the present investigation, Class Cflyash obtained from Neyveli thermal plant which is by product obtained during the burning of coal is used.

### 3.6 Water

The water which is fit for drinking should be used for making concrete.

## 4. CONCRETE MIX DESIGN

Concrete mix design for M20, M30 and M60 grades of concrete was done according to IS: 10262 and presented in Table 6.

**Table 6 Quantities of Materials Required per 1 cum of Ordinary Concrete**

| Grade of Concrete | Cement (kg) | Fine Aggregate (kg) | Coarse Aggregate (kg) | Water (Lts) | Admixture |
|---|---|---|---|---|---|
| M 20 | 320 | 810 | 1026 | 182 | 1.20 |
| M 30 | 370 | 744 | 1125 | 170 | 2.20 |
| M 60 | 504 | 679 | 1101 | 138 | 3.00 |

Pan mixer is used for the uniformity of the mix. The casting of the specimen of standard size of 150x150x150 mm cubes and 150mm diameter x 300mm height cylinders moulds are used. The curing is done to achieve a better strength of concrete.

## 4.1 Testing of Specimens

The testing was done on a hydraulically operated digital compression testing machine of 2000 kN capacity for compressive strength.The determination of compressive strength and split tensile strength was performed as per standard and shown in Figures 1 and 2.

**Fig. 1 Evaluating the Compressive Strength**

**Fig. 2 Evaluating the Split Tensile Strength**

## 4.2 Water Sorptivity Evaluation

The standard procedure adopted to carry out the test in the specimen size of 100 x100x100 mm after it has achieved curing at 28 days. The cubes were stored in an oven at 105°C for 72 hours, and were cooled at room temperature for 24h. A protective coating of epoxy resin was applied to the four faces of the cube to prevent water from penetrating through the sides.

## 5. RESULTS AND DISCUSSION

### 5.1 Compressive Strength

The compressive strength for M20, M30 and M60 grades with different percentages of flyash with natural and recycled coarse aggregate at 28 days are presented in Table 7. The control concrete is compared with varying percentages of cement with fly ash and coarse aggregate with recycled aggregate. M20 grade of concrete with 50% of fly ash achieved the required strength. Depending upon the strength requirement the percentage can be fixed for the structural components and it is sustainable. Utilizingrecycled aggregate along with fly ash allows for achieving sustainable concrete. Even high strength can be achieved by using recycled aggregate. When compared with normal aggregate there is less strength achieved in using recycled aggregate.Figure 3 represents the compressive strength of different grades of concrete with varyingpercentages of fly ash with natural and recycled coarse aggregate.

**Table 7 Compressive Strength for Various Percentages of Fly Ash**

| Grade of Concrete | Compressive Strength @ 28 days, N/mm$^2$ | | | | | |
|---|---|---|---|---|---|---|
| | 0% | 10% | 20% | 30% | 40% | 50% |
| M20 | 27.53 | 26.09 | 27.67 | 26.46 | 25.08 | 24.39 |
| MR20 | 26.04 | 25.51 | 25.03 | 24.97 | 24.20 | 23.85 |
| M30 | 38.41 | 36.81 | 37.31 | 36.99 | 36.41 | 35.84 |
| MR30 | 36.89 | 35.19 | 35.01 | 34.81 | 34.06 | 33.27 |
| M60 | 70.39 | 67.04 | 68.48 | 66.04 | 65.92 | 64.61 |
| MR60 | 66.50 | 65.91 | 64.57 | 64.26 | 63.89 | 63.09 |

***Note:*** *MR: Mix using Recycled aggregate*

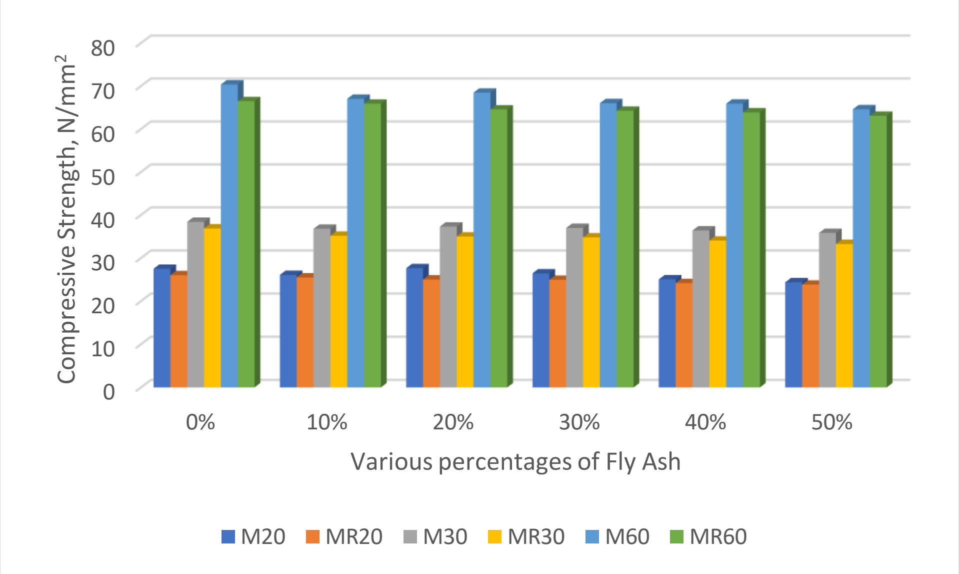

**Fig. 3Compressive Strength of Different Grades of Concrete with Varying Percentages of Fly Ash with Natural and Recycled Coarse Aggregate**

### 5.2 Split Tensile Strength

The split tensile strength for M20, M30 and M60 grades with different percentages of fly ash using natural and recycled coarse aggregate at 28 days are presented in Table 8 and figure 4.

**Table 8 Split Tensile Strength for various percentages of Fly Ash**

| Grade of Concrete | Split Tensile Strength, N/mm$^2$ | | | | | |
|---|---|---|---|---|---|---|
| | 0% | 10% | 20% | 30% | 40% | 50% |
| M20 | 3.08 | 3.14 | 2.75 | 2.65 | 2.56 | 2.44 |
| MR20 | 2.98 | 3.01 | 2.55 | 2.44 | 2.37 | 2.31 |
| M30 | 3.14 | 3.43 | 3.21 | 3.08 | 4.07 | 3.02 |
| MR30 | 3.01 | 3.25 | 3.06 | 3.07 | 3.85 | 2.96 |
| M60 | 4.79 | 5.06 | 5.58 | 5.33 | 5.57 | 4.63 |
| MR60 | 4.09 | 4.63 | 4.88 | 4.39 | 4.42 | 3.86 |

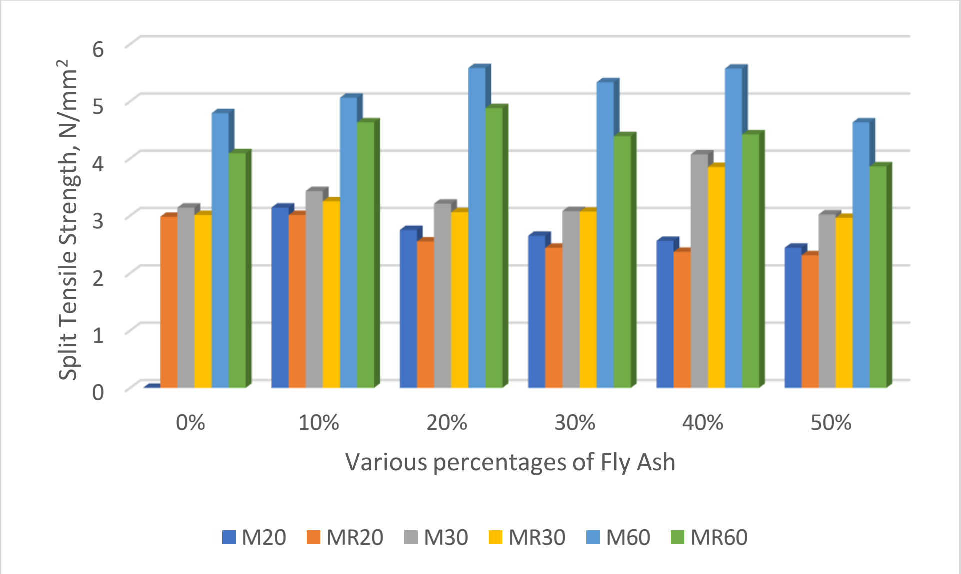

**Fig. 4Split Tensile Strength of Different Grades of Concrete with Varying Percentages of Fly Ash with Natural and Recycled Coarse Aggregate**

### 5.3 Water Sorptivity

The water split tensile strength for M20, M30 and M60 grades with different percentages of fly ash mixed with natural and recycled coarse aggregate at 28 days. Water sorptivity is higher with recycled aggregate andis presented in Table 9 and figure 5.

**Table 9 Water Sorptivity for various percentages of Fly Ash**

| Grade of Concrete | Water Sorptivity | | | | | |
|---|---|---|---|---|---|---|
| | 0% | 10% | 20% | 30% | 40% | 50% |
| M20 | 0.13 | 0.11 | 0.10 | 0.08 | 0.07 | 0.05 |
| MR20 | 0.14 | 0.12 | 0.11 | 0.09 | 0.08 | 0.06 |
| M30 | 0.11 | 0.10 | 0.08 | 0.07 | 0.05 | 0.04 |
| MR30 | 0.12 | 0.11 | 0.09 | 0.08 | 0.07 | 0.05 |
| M60 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.01 |
| MR60 | 0.07 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 |

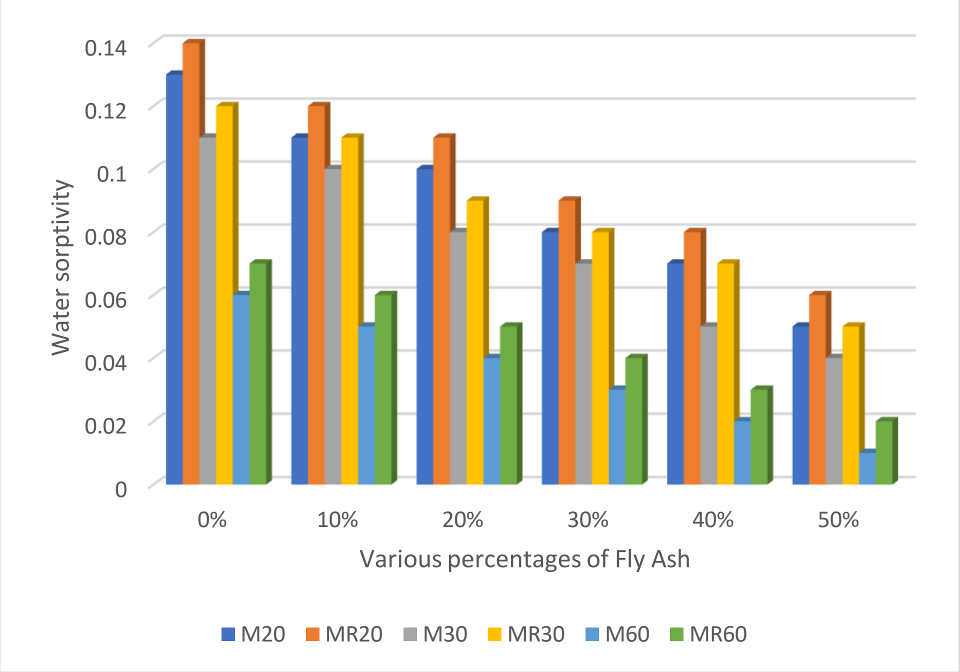

**Fig. 5Water sorptivity of Different Grades of Concrete with Varying Percentages of Fly Ash with Natural and Recycled Coarse Aggregate**

## 6. CONCLUSIONS

In the majority of cases, the concrete's 28-day compressive strength was only slightly higher or lower than that of the control concrete.Workability of concrete decreases as the proportion of fly ash increases.Concretes with increasing percentages of fly ash replacement for cement displayed lower cumulative water absorption values, indicating lesser porosity in the cover zone.It is possible to replace up to 50% of the cement with fly ash without noticeably lowering the concrete's compressive strength. The parameters of absorption surpass those of the control mixes.The use of the waste material and a reduction in $CO_2$ emissions will result from a higher percentage of replacement of cement.By utilizing recycled aggregate sustainable concrete can be achieved.The strength of using recycled aggregate with fly ash achieves the grade but is lower than the normal concrete.

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