An Experimental Study on Polymer Impregnated Concrete with Fly Ash

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Abstract. Fly ash can be used in research paper to partly substitute cement for three separate types of concrete, M20, M40, and M60. Until the curing process is finished, the samples are made to undergo partial polymer impregnation and dried for 8 hours. For performance criteria, compressive strength, flexural strength and break structural stress, the concrete samples are then tested. The values obtained are compared with 0 percent of fly ash concrete cast specimens. Also, referred to as a nominal mix in this paper. Fly ash is chosen to perform this experiment because it is an eco-friendly material. It is a waste product that contributes to sustainability and incorporation of it in concrete is possible due to its pozzolanic characteristic. For the impregnation process, the polymers used are polyester and styrene. The experimental is conducted to evaluate the effect of fly ash onto cement along with partial polymer impregnation and their effects on strength properties. The research is also an initiative to contribute to sustainability. After the completion of the experiment, it can be observed that the use of fly ash as a partial replacement of cement does not negatively affect the strength parameters, alternatively, in the long run, it can be used to obtain strength higher than the nominal mix. The impregnation of polymer does have a significant impact on the concrete samples in terms of strength quality. The use of cement in concrete accounts for about 40% carbon dioxide emission, causing a greenhouse effect. On the other hand, the partial substitution of fly ash reduces the amount of cement needed in the construction process without compromising the performance of concrete. Even, the treatment of fly ash takes care of that. Due to the clear existence of fly ash, this form of selective replacement of cement in concrete can be used extensively.

Keywords: Polymer impregnation, Ash, strength of compression, flexural, quality of break stress, stability and fine aggregates

1. Introduction
There has been an increase in awareness of the importance of sustainability over the past few decades. With today's society facing issues such as climate change, scarcity of water, waste disposal, global warming, reduction in air quality, among other topics. Every industry is adopting methods and experimenting with materials and alternatives that do not harm the environment. So is the case with the construction industry, where incorporation of eco-friendly techniques is of utmost importance, because of the resources it consumes. Statistically, it is observed that the construction industry accounts for about 40% of carbon dioxide emission all over the world [1]. This is primarily due to the resource-consuming manufacturing process of the cement. Cement has high embodied energy due to its demand in the construction of buildings. Research of substitute materials is taking place to reduce
the amount of cement used and at the same time, ensuring that it is economical, does not affect the performance of concrete and the quality of the construction.

Fly ash contains aluminous and siliceous material along with other properties that make it compatible to be used in the making of concrete [4]. The many benefits of using fly ash include and is not limited to reduced bleeding of concrete, higher strength gain with the increase in age of concrete, reduction in permeability, increase in durability, and better workability [5]. Polymer concrete is another variation of concrete that is developed to impart desired characteristics in concrete. There are different techniques in which polymer can be instigated in the concrete. One such method is the partial impregnation of the polymer [6]. This method improves the accomplishment of the concrete by enhancing the strength and durability of concrete. It also protects the construction from acid attacks, increases bond properties, and have lesser maintenance issues in general. Polymer concrete contributes to sustainability by maximizing the usage of resources, safeguarding the environment, improving the quality and the life span of the building [7]. In addition to this, though polymer in concrete is toxic and flammable, once the concrete is set and hardened, they do not impart any characteristics associated with toxicity [2]. Styrene is a standard monomer used to reduce the viscosity of unsaturated resins. However, this chemical unit can hurt the environment, the current research in this field has ascertained that presently, the better step advancing to sustainability is styrene reduction and not replacement as it may result in more harm to the environment [3]. Thus, the choice to experiment with partial impregnation instead of full impregnation.

The values obtained are compared with regular concrete, that contains no trace of fly ash, and no polymer impregnation takes place. This is also referred to as the nominal mix [8]. The following section presents the methods used to experiment, and the design mix ratio of the three grades of concrete, namely, M20, M40, and M60. In the results section, the results of the strength parameters are presented. The specimens are compared with regular concrete [9]. The results are then analyzed and conveyed along with the future scope in the discussion section. This study is then summarized and concluded in the fifth section of this paper.

2. Methods

2.1 Materials

2.1.1 Cement and Fly Ash:

This grade of ordinary Portland cement has the most exceptional particle size distribution, which results in an increase in strength and durability to the structures [11]. Fly ash is used to replace 15% of cement partially. [10] Fly ash is procured from a single source and tested along with cement for its properties. Table 1 represents the properties of cement and Fly ash. The preliminary tests for this material are conducted, and the features are listed below:

| Properties            | Cement | Fly Ash |
|-----------------------|--------|--------|
| Fineness              | 3.1    | 3.5    |
| Initial setting time (min) | 35     | 45     |
| Final setting time (min)  | 450    | 280    |
| Specific Gravity      | 3.13   | 2.51   |

2.1.2 Fine Aggregate:
The aggregates were tested for its physical properties and ensure that they conformed to IS code. The sieve analysis conducted confirmed that the aggregates belong to Zone-III area.

2.1.3 Coarse Aggregate:
For the coarse aggregate, 12.5mm size aggregate is used. Table 2 represents the Properties of Coarse Aggregate. The characteristics of this sum are given below.
Table 2: Properties of Coarse Aggregate

| Properties    | Coarse Aggregate |
|---------------|------------------|
| Specific Gravity | 2.9             |
| Fineness Modules          | 7.47            |
| Water Absorption (%)     | 1.45            |

2.1.4 Silica Fumes:
For the M-60 design mix, silica fumes are used to replace 5% of cement apart from the fly ash replacement. [12] The quality of silica fumes is outstanding, resulting in the concrete being more durable with fewer voids. Table 3 represents the Properties of Silica Fumes.

Table 3: Properties of Silica Fumes

| Property | Silica Fumes |
|----------|--------------|
| Colour   | Grey         |
| Specific Gravity | 2.2          |

2.1.5 Super Plasticizer:
TECH MIX- 550 is used in M60 grade concrete to increase the workability of concrete. 1.5% of this superplasticizer is added as a chemical admixture to the concrete.

2.2 Design Mix Ratio
The ratios for the grades of concrete were calculated with IS 10262:2009 and IS 456:2000. Based on these calculations, 5% of silica fumes and 1.5% of superplasticizer was added to the concrete. Table 4 represents the Design Mix Ratios.

Table 4: Design Mix Ratios

| Grade | Mix Ratio | Replacement  | Water-Cement Ratio | Admixture                        |
|-------|-----------|--------------|--------------------|----------------------------------|
| M20   | 1:2.17:2.35 | 15% fly ash 0.5 | -                  |                                  |
| M40   | 1:1.58:1.86  | 15% fly ash 0.4  | -                  |                                  |
| M60   | 1:1.59:2.11  | 15% fly ash 0.3  | 5% silica fumes and 1.5% super plasticizer |                                  |

2.3 Polymer Impregnation of Concrete
For the partial impregnation of polymer in concrete, the polymers used are polyester and styrene. The polyester resin is highly viscous, and the addition of styrene monomer reduces the viscosity and catalyzes the impregnation of the polymer. [12] For the partial impregnation, the specimens are made to undergo surface impregnation by placing the sample in the polymer and then covering them with a plastic sheet to avoid evaporation. The samples are made to dry for 8 hours and then tested for their strength characteristics.

2.4 Testing
After the design mix was calculated, the necessary materials were added in estimated proportions and cast in cube, prism and cylinder. The size of the cube was 150mmX150mmX150mm. The volume of the prism was 500mmX100mmX100mm. The size of the cylinder used was of height 200mm and diameter 100mm. After the concrete was cast in these moulds, they were allowed to sit for 24 hours. After the completion of 24 hours. [13] For the specimens were cured for 14, and 28 days. For each grade of concrete, 18 samples were cast, nine specimens for seven days and nine specimens for 28 days. Three for each type of mould. The same procedure was followed for the nominal mix as well. After the curing process, the specimens were dried in the oven and made to undergo partial impregnation of the polymer. [14] After the impregnation of the polymer, the samples were tested. The nominal mix specimens were tested as well, and the observations recorded were tabulated, compared and analyzed.
3. Results

3.1 Slump Cone Test

Table 5: Slump of Concrete and Fly Ash

| Grade of Concrete | M20 | M40 | M60 |
|-------------------|-----|-----|-----|
| Slump of nominal mix (mm) | 53  | 48  | 79  |
| The slump of fly ash replaced concrete. | 56  | 52  | 83  |

Table 5 represents the Slump of Concrete and Fly Ash. The slump test is performed to check the consistency of concrete. The slump value is determined as per IS code 1199:1959 in India. It checks the workability of a newly prepared batch of concrete. [15] It also allows us to determine whether the mix prepared is in proper proportion or not. This makes it easier to determine the outcome of the hardened concrete. Here, the slump cone test is performed for three grades of concrete, M20, M40, and M60.

3.2 Compressive Strength test

Table 6 shows the Compressive Strength Test Results and figure 1 show the Comparison of Regular concrete with Fly ash concrete impregnated in the polymer.

Table 6: Compressive Strength Test Results

| Grade of Concrete | S. no. | 7 days | 28 days | 7 days | 28 days | 7 days | 28 days |
|-------------------|-------|--------|--------|--------|--------|--------|--------|
|                  |       |        |        |        |        |        |        |
|                  |       | 15.6   | 21.0   | 15.20  | 27.89  |
| M20              | 1     | 15.54  | 22.3   | 14.70  | 26.54  |
|                  | 2     | 22.78  | 45.78  |
|                  | 3     | 23.56  | 46.92  |

| Grade of Concrete | S. no. | 23.24 | 41.2  | 22.78  | 45.78  |
|-------------------|-------|------|------|--------|--------|
|                  |       | 15.58 | 22   | 14.35  | 25.7   |
| M40              | 1     | 22.88 | 44.6 |
|                  | 2     | 24.53 | 39.8 |
|                  | 3     | 22.31 | 41.10 |

| Grade of Concrete | S. no. | 56.8 | 65.9  | 54.28  | 66.39  |
|-------------------|-------|------|------|--------|--------|
|                  |       | 65.8 | 51.87 | 73.36  |

Table 6 shows the Compressive Strength Test Results and figure 1 show the Comparison of Regular concrete with Fly ash concrete impregnated in the polymer.
3.3 Flexural strength test

Table 7 shows the Compressive Strength Test Results and figure 2 show the Comparison of Flexural strength for Nominal mix Vs Fly ash based PIC.

| Grade of Concrete | S.no. | Flexural strength in (N/mm²) | Average Flexural strength in (N/mm²) | Flexural strength in (N/mm²) | Average Flexural strength in (N/mm²) |
|-------------------|------|-----------------------------|-------------------------------------|-----------------------------|-------------------------------------|
|                   |      | Nominal Mix                 | Nominal mix                         | 15% Fly ash with PIC        | 15% Fly ash with PIC                |
|                   | 14 days | 28 days                     | 14 days                             | 28 days                     | 14 days                             |
| M20               | 1     | 5.5                         | 10                                  | 5.75                        | 9.58                                | 4.7                                  | 12.25                                |
|                   | 2     | 5.75                        | 9.25                                | 6.79                        | 13.20                                | 6.5                                  | 14.59                                |
|                   | 3     | 6                           | 9.5                                 | 6.45                        | 15.65                                | 8.3                                  | 18.67                                |
| M40               | 1     | 6.25                        | 9.25                                | 7.41                        | 10.5                                 | 6.5                                  | 14.59                                |
|                   | 2     | 8.25                        | 11.75                               | 6.25                        | 14.93                                | 8.3                                  | 18.67                                |
|                   | 3     | 7.75                        | 10.5                                | 6.45                        | 15.65                                | 8.3                                  | 18.67                                |
| M60               | 1     | 10                          | 16.5                                | 9.16                        | 15.3                                 | 7.45                                 | 19.25                                |
|                   | 2     | 8.5                         | 14.5                                | 8.75                        | 18.49                                | 8.3                                  | 18.67                                |
|                   | 3     | 9                           | 9                                   | 8.78                        | 18.11                                | 8.3                                  | 18.67                                |

Figure 2: Comparison of Flexural strength for Nominal mix Vs Fly ash based PIC
3.4 Split Tensile Strength Test

Table 8 shows the Compressive Strength Test Results and figure 3 show the Comparison of Split tensile strength for Nominal mix vs Fly ash based PIC.

Table 8: Compressive Strength Test Results

| Grade of Concrete | S. no. | Nominal Mix | Average Split tensile strength in (N/mm²) | Average Split tensile strength in (N/mm²) | Split tensile strength in (N/mm²) | Average Split tensile strength in (N/mm²) |
|-------------------|-------|-------------|------------------------------------------|------------------------------------------|----------------------------------|------------------------------------------|
|                   |       |             | 7 days 28 days                            | 7 days 28 days                            | 7 days 28 days                    | 7 days 28 days                            |
| M20               | 1     | 2.1         | 2.8                                       | 2.14                                     | 2.46                             | 3.02                                     |
|                   | 2     | 2.2         | 2.7                                       | 2.82                                     | 2.01                             | 3.19                                     |
|                   | 3     | 2.0         | 2.9                                       |                                          | 2.11                             | 3.25                                     |
| M40               | 1     | 2.5         | 4.5                                       | 2.55                                     | 2.50                             | 4.34                                     |
|                   | 2     | 2.3         | 4.1                                       | 4.28                                     | 2.62                             | 4.97                                     |
|                   | 3     | 2.7         | 4.1                                       |                                          | 2.78                             | 4.80                                     |
| M60               | 1     | 4.8         | 6.1                                       | 4.53                                     | 5.23                             | 7.31                                     |
|                   | 2     | 4.1         | 6.2                                       | 6.21                                     | 5.20                             | 6.50                                     |
|                   | 3     | 4.5         | 6.3                                       |                                          | 4.10                             | 6.32                                     |

Figure 3: Comparison of Split tensile strength for Nominal mix vs Fly ash based PIC

4. Summary and Conclusion

In previous works, it has been observed that 15%-25% of fly ash replacement is advised as it does not affect the strength of conventional concrete drastically in terms of early strength gained. The three
classes of concrete used in this experiment are M20, M40, and M60. The cast specimens are tested for their compressive strength, flexural strength, and split tensile strength. The cube moulds of size (150mmX150mmX150mm), rectangular beams of size (500mmX100mmX100mm) and cylindrical shapes of size (200mmX100mm) and allowed to sit for 24 hours. The cube and cylindrical concrete specimens are cured for 7, and 28 days. The strength values are compared with specimens that are cast with 0% fly ash, and have not undergone polymer impregnation but have been cast, and cured in the same way, and in this paper is referred to as nominal mix. Through this experimental research, it can be observed that for seven days the fly ash specimens that have been impregnated with the polymer can achieve compressive strength, flexural strength, and split tensile strength as that of the nominal mix. This is attributed to the advantage obtained by the impregnation of the polymer. Typically, due to the leisure strength gain of fly ash, the seven days strength gained is low in comparison with conventional concrete. However, the partial impregnation of polymer had caused the specimens to gain strength as that of traditional concrete. This pattern is observed consistently for all three grades of concrete and strength parameters. On the other hand, for the 28-day strength, the compressive strength, flexural strength, and split tensile strength shows values higher than conventional concrete. The difference in strength gain is higher than that seen in 7 days strength difference. This difference is due to fly ash gaining strength over a while. Thus, it can be concluded that the impregnation of polymer contributes to achieving strength, along with improving the quality of concrete.

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