Study on Strength Properties of Concrete using Pumice Powder Pozzolan and Polypropylene Fibers

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Abstract. The construction industry is flourishing day by day, as a result, cement consumption also increases. Since cement production causes carbon footprint, partial replacement using waste materials from various industries is one of the solutions. Pumice powder, generated by the stone processing industry, is an inert by-product possessing excellent cementitious characteristics. Utilisation of pumice powder in concrete can reduce the cost of construction and at the same time address the waste disposal problem. The fiber dispersion into concrete is one of the techniques to further improve the ductile properties of concrete. This study is focused on the strength properties of pumice powder pozzolan concrete reinforced with polypropylene fibers. Mechanical strength characteristics were evaluated for normal and varying contents of pumice powder and polypropylene fiber added mix after 7 and 28 days of curing. The results indicate that the strength properties of the modified mix has improved considerably. The significance of this study is to promote the usage of by-product waste as a replacement for cement thereby reducing CO2 emissions and thus resulting in the development of environmentally friendly concrete.

1. Introduction

To decrease the carbon footprint due to cement manufacturing and construction industries, one of the best ways is to reduce the cement used in concrete production. More than 4 billion tons of cement are produced annually for construction purposes [1]. This can be reduced by utilising alternative materials in concrete production which is called as supplementary cementitious materials (SCMs). Different types of wastes like industrial wastes, agricultural wastes, natural minerals, stone powders, and dust contributes to the production of an environment-friendly concrete [1]. The usage of SCMs in construction has the added advantage that it reduces excessive disposal of waste into the landfills.

This paper concentrates on the utilisation of one such industrial by-product of the stone processing industry for reducing CO2 emission. Pumice powder (PP) is a powder ground form of natural lightweight-aggregate pumice which is formed by rapid cooling and solidification of volcanic lava. The notable characteristics which makes pumice a lightweight-aggregate are its reduced density, better thermal insulation and fire resistance, lower permeability and shrinkage, reasonable elasticity and porous structure [2, 3]. But when pumice as such is used without powdering in concrete, the strength improvement is found to be marginal. As the particle size of PP decreases, the rate of hydration, pozzolanic reaction and compressive strength increases [4]. Thus the pozzolanic activity of PP improves the mechanical characteristics of concrete [1]. Also, the utilisation of natural pumice pozzolan in concrete reduces global warming potential and improves the air quality index [5].
The fiber dispersion into concrete is one of the techniques to improve concrete’s ductility properties like flexural capacity, crack control, etc. Polypropylene fibers are 3D fibers made from byproducts of petroleum. These fibers are nowadays well accepted in the construction industry due to the properties which they impart like high tensile strength, flexural strength, impact strength, toughness, etc. These fibers also improve the failure mode of concrete by helping in crack control [6]. These fibers have a twisted geometry thereby improving mechanical anchorage with the cementitious matrix [6]. They even show better strength and ductility properties when subjected to very high temperatures and exposure periods [7].

This study presents the results of the research conducted to assess the effect of partial replacement of cement with PP, along with a 3D fiber addition on mechanical strength characteristics of concrete. This work will provide a platform to investigate the performance of PP in the development of environment-friendly concrete thereby promoting its utilisation for the development of infrastructures.

2. Experimental program

2.1. Materials

The raw materials utilised in the study include cement, PP, fine aggregate, coarse aggregate, polypropylene fiber, superplasticiser, and water.

53 grade OPC (Ordinary Portland Cement) conforming to IS 12269-1987 was used throughout in this study. The properties of cement such as fineness, specific gravity, standard consistency, initial and final setting times were determined and are given in table 1.

Pumice powder which is an industrial byproduct of the stone processing industry i.e. pumice rock in powdered form is utilised as partial replacement of cement in this study. Color of pumice is normally found to be grey or white and ranges depending on the chemical composition of pumice. Properties of PP are shown in table 1.

| Properties | Cement | PP |
|------------|--------|----|
| Fineness   | 7%     | 6.8% |
| Standard Consistency | 28% | 32.5% |
| Initial Setting time | 75 minutes | 50 minutes |
| Final Setting time | 360 minutes | 360 minutes |
| Specific gravity | 3.1 | 2.84 |

Manufactured sand (M-sand) conforming to Zone II, passing 4.75 mm and retained on 150 μm sieve was used as fine aggregate in this study. The maximum size of the coarse aggregate used for the study is 20 mm. The physical properties of aggregates are shown in table 2.

| Properties | Fine aggregate | Coarse aggregate |
|------------|----------------|-----------------|
| Fineness Modulus | 4.708 | 5.22 |
| Grade zone | II | - |
| Specific Gravity | 2.645 | 2.9 |
| Bulk density | 1820 kg/m³ | 1542 kg/m³ |
| Porosity | 32% | 44.3% |
| Void ratio | 0.473 | 0.91 |

Polypropylene fibers are 3D fibers that provide reinforcement in x, y and z planes. Properties of PF are shown in table 3.
Table 3. Properties of polypropylene fiber (Source: Supplied by Manufacturer).

| Properties               | Value         |
|--------------------------|---------------|
| Colour                   | White         |
| Length                   | 12mm          |
| Diameter                 | 24-44 micron  |
| Aspect ratio approx.     | 500           |
| Alkali resistance        | 100% alkali proof |
| Acid and salt resistance | High          |

Superplasticisers are chemical admixtures used to modify the workability property of concrete. In the present study, workability was improved by using a superplasticiser (SP) named Conplast SP430. The amount of SP dosage used in concrete is taken as 1.2% of the weight of the cement.

2.2. Mix proportion and specimen preparation

Test specimens were cast using optimum water-cement ratio for each mix. The optimum replacement of cement with pumice powder (PP) is determined by casting normal and PP mortar (PPM) cubes of size 70.6 mm × 70.6 mm × 70.6 mm in 1:3 mix proportion as per IS:4031 (Part 6)-1988. Cement is replaced with PP at 0% (0PP), 5% (5PP), 10% (10PP), 15% (15PP) and 20% (20PP). The mix proportion of PPM cube specimens and PP-PF concrete specimens are given in table 4 and table 5 respectively.

Table 4. Mix proportion of PPM

| Mix designation | Cement (kg) | PP (kg) | Sand (kg) | Water (kg) |
|-----------------|-------------|---------|-----------|------------|
| 0PP             | 1.2160      | 0       | 4.05      | 0.60       |
| 5PP             | 1.1552      | 0.0608  | 4.05      | 0.62       |
| 10PP            | 1.0944      | 0.1216  | 4.05      | 0.62       |
| 15PP            | 1.0336      | 0.1824  | 4.05      | 0.62       |
| 20PP            | 0.9728      | 0.2432  | 4.05      | 0.62       |

Table 5. Mix proportion of PP-PF concrete.

| Mix designation | Cement (kg) | PP (kg) | PF (kg) | Sand (kg) | Coarse Aggregate (kg) | SP (kg) | Water (kg) |
|-----------------|-------------|---------|---------|-----------|-----------------------|---------|------------|
| 0 PP + 0 PF     | 23.29       | 0       | 0       | 38.04     | 63.67                 | 0.279   | 10.2       |
| 10 PP + 0 PF    | 20.961      | 2.329   | 0       | 38.04     | 63.67                 | 0.279   | 10.2       |
| 10 PP + 1 PF    | 20.961      | 2.329   | 0.484   | 38.04     | 63.67                 | 0.279   | 10.2       |
| 10 PP + 1.25 PF | 20.961      | 2.329   | 0.605   | 38.04     | 63.67                 | 0.279   | 10.2       |
| 10 PP + 1.5 PF  | 20.961      | 2.329   | 0.726   | 38.04     | 63.67                 | 0.279   | 10.2       |
| 10 PP + 1.75 PF | 20.961      | 2.329   | 0.847   | 38.04     | 63.67                 | 0.279   | 10.2       |

Along with optimum PP content, polypropylene fibers (PF) were added at 0% (10 PP + 0 PF), 1% (10 PP + 1 PF), 1.25% (10 PP + 1.25 PF), 1.5% (10 PP + 1.5 PF) and 1.75% (10 PP + 1.75 PF) of total volume of concrete to make pumice powder- polypropylene fiber (PP-PF) concrete. M30 grade of mix proportion 1: 1.47: 2.59 was adopted for concrete specimens. For each mix, the specimens cast are: 6 cube specimens (150 mm × 150 mm × 150 mm) each for compressive strength test after 7 days and 28 days of curing, 3 samples of cylinder (150 mm dia × 300 mm height) each for split tensile strength test after 28 days of curing and 3 beams (500mm × 100 mm×100 mm) each for flexural strength test after 28 days of curing. Specimens were removed from moulds after 24 hours and then cured under water until testing at 7 and 28 days.
2.3. Test methods

2.3.1. Compressive strength test on mortar and concrete specimens. Compressive strength test was conducted on PPM cubes as per IS 12269:2013. The optimum content of PP was found from samples which gave maximum average compressive strength value. Compressive strength test was also conducted on concrete cube specimens as per IS 516:1959. 3 cubes for 7 day and 3 cubes for 28 days were tested for each mix containing optimum content of PP and varying percentage of PF. Optimum PF content was obtained from the sample which gave maximum average compressive strength value.

2.3.2. Split tensile strength test and Flexural strength test on concrete specimens. Split tensile strength test was conducted after 28 days of curing on cylindrical specimens for determining the tensile strength of concrete as per IS 5816:1999. Three beam specimens were cast and tested after 28 days of curing to determine the flexural strength of concrete as per IS 516:1959 specification for all mixes.

3. Results and discussions
Tests were performed to investigate the effect of different PP and PF content on strength of PP-PF concrete.

3.1. Compressive strength
The variation in compressive strength of PPM and PP-PF concrete specimens are formulated in table 6 and table 7, respectively. The graphical representation of results in PPM and PP-PF concrete specimens is shown in figure 1 and figure 2, respectively.

Table 6. Variation in compressive strength with varying PP content.

| Mix designation | 7-day Compressive Strength (N/mm$^2$) | 28-day Compressive Strength (N/mm$^2$) |
|-----------------|--------------------------------------|--------------------------------------|
| 0 PP            | 37.31                                | 53.36                                |
| 5 PP            | 40.53                                | 59.10                                |
| 10 PP           | 42.53                                | 61.39                                |
| 15 PP           | 39.72                                | 57.82                                |
| 20 PP           | 38.11                                | 54.97                                |

Table 7. Variation in compressive strength with varying PF content.

| Mix designation | 7-day Compressive Strength (N/mm$^2$) | 28-day Compressive Strength (N/mm$^2$) |
|-----------------|--------------------------------------|--------------------------------------|
| 0 PP + 0 PF     | 24.44                                | 39.28                                |
| 10 PP + 0 PF    | 26.77                                | 40.86                                |
| 10 PP + 1 PF    | 27.24                                | 42.20                                |
| 10 PP + 1.25 PF | 28.44                                | 44.22                                |
| 10 PP + 1.5 PF  | 29.96                                | 46.67                                |
| 10 PP + 1.75 PF | 28.20                                | 43.1                                 |

Figure 1. Compressive strength of PPM.

Figure 2. Compressive strength of PP-PF Concrete.
With the increase in PP content, compressive strength of mortar specimens increases up to 10% PP mix, which gave a maximum compressive strength of 42.53 N/mm² and 61.39 N/mm² at 7 and 28 days respectively. Further, the strength is found to be slightly decreasing.

The compressive strength of concrete specimens is found to be increasing with the increase in PF content. 1.5% is the optimum content of PF which gave a maximum compressive strength of 29.96N/mm² and 46.67N/mm² at 7 and 28 days, respectively along with 10% PP content. Further, the strength is found to be slightly decreasing.

The silica in PP combines with calcium hydroxide of cement, in the presence of water to form the stable compound calcium silicate which is having cementitious properties [8]. This pozzolanic action of PP contributes to the enhancement of strength in PP added specimens. Hence addition of PP along with cement is beneficial.

3.2. Split tensile strength and Flexural strength

The results of the 28-day split tensile strength and flexural strength test in PP-PF concrete specimens for various mixes are shown in table 8. Graphical representations of split tensile strength and flexural strength tests are shown in figure 3 and figure 4, respectively.

| Mix designation | Split tensile strength (N/mm²) | Flexural strength (N/mm²) |
|-----------------|-------------------------------|----------------------------|
| 0 PP + 0 PF     | 3.39                          | 5.6                        |
| 10 PP + 0 PF    | 3.80                          | 5.8                        |
| 10 PP + 1 PF    | 4.24                          | 6.6                        |
| 10 PP + 1.25 PF | 4.81                          | 8.0                        |
| 10 PP + 1.5 PF  | 5.65                          | 9.6                        |
| 10 PP + 1.75 PF | 4.52                          | 7.2                        |

Variation in tensile and flexural strength shows a trend similar to that of compressive strength. The 28 day split tensile strength and flexural strength increases with increase in PF content. Maximum split tensile strength was obtained as 5.65 N/mm² with 10% PP and 1.5% PF content. A maximum flexural strength of 9.6 N/mm² was obtained for 10% PP and 1.5% PF content.

4. Conclusions

The study is focused on finding the combined effect of pumice powder and polypropylene fiber in concrete along with finding the optimum content for maximum strength development. The key findings of the study are as follows:

- Pumice powder exhibits pozzolanic characteristics similar to cement.
- With the addition of pumice powder, the compressive strength increased marginally and optimum replacement content of cement with PP was found to be 10%.
- The substitution of cement with cost-effective material like pumice powder improved the overall strength behavior of concrete although the strength improvement was marginal.
With the addition of polypropylene fiber in concrete along with optimum content of pumice powder, mechanical strength characteristics increased and the optimum content of PF is found as 1.5%.

The increase in compressive strength, split tensile strength and flexural strength for modified mix with optimum of PP and PF contents at 28 days of curing is 19%, 67%, and 72%, respectively.

Fiber addition in concrete improved the tensile as well as the flexural properties of concrete. Hence it can be concluded that strength properties of concrete incorporated with waste pumice powder and polypropylene fiber increased considerably as compared to normal concrete.

5. References

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