Experimental investigation of the effect of curing compound on self-compacting concrete properties

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Abstract. Lack of proper compaction and curing in cement concrete may lead to the poor strength and durability characteristics. In this paper the effect of curing compound on self-compacting concrete properties has been investigated. The experimental work was performed in two phases. In the 1st phase the optimum superplasticizer (SP) dosage was determined for the maximum compressive strength and in the second phase the effect of curing agent (PEG4000) on the strength at optimum SP dosage was investigated. Additionally workability, split tensile strength and flexural strength were also investigated at different SP and curing agent dosage. The test results showed that the maximum compressive strength of 27.7MPa and 39.48MPa was obtained at 1% SP dosage after one and four weeks of testing. The splitting tensile strength and flexural strength also showed maximum improvement at 1% SP dosage. The maximum mechanical strength of the self-cured concrete in terms of compression, tension and flexure was obtained at 1.6% dosage of PEG4000. The workability got reduced as the dosage of curing compound was increased from 1.2% to 1.8%. Therefore, the self-compacted and self-cured concrete for the maximum strength can be developed at an optimum dosage of 1% PCE based superplasticizer and 1.6% PEG4000 based curing compound.

Keywords: Cement concrete, workability, mechanical strength, superplasticizer, curing compound.

1. Introduction

Heavily reinforced structures require more workable concrete so as to fill all the voids and provide a dense compact structure without compromising with the strength [1]–[5]. Self-Compacting Concrete helps in overcoming this requirement of workability and strength at the same time. The strength and durability properties of the self-compacting concrete, developed by Okamura in 1998, envisioned to improve the durability characteristics of concrete structures [6]. The ability of the self-compacting concrete to flow and compact by its own weight without the loss of the integrity of the ingredients of the concrete and without bleeding is due to the high workability of the mix [7]–[11]. Various research works have reported that the use of high range water reducers can provide extremely high workability at low water-cement ratio and they also help in improving the strength to some extent [12]–[16]. Different types of superplasticizer are used to improve the workability of the different types of concrete mixes [17]–[21]. It is a well-known fact that curing plays a vital role in deriving the strength and durability characteristics of cement concrete [22]–[24]. Many a times, the curing of the cement concrete structures gets ignored due to lack of
supervision, poor workmanship, inaccessible sections and high cost of good quality water. Self-curing or internal water retention or internal curing is a system which can be utilized to arrange for extra moisture in concrete which in turn facilitate more real hydration of cement and less self-desiccation [25]–[27]. Along with the curing agent the nature and type of aggregates also has substantial impact on the properties of concrete [28]–[30]. The strength and durability properties of the concrete can be improved by improving the pore structure of the concrete which is mostly dependent on the curing of concrete [31], [32]. The choice of water also plays a very important role in compaction and curing of the concrete [33].

The aim of this investigation is to fix the optimum dosage of the PCE based superplasticizer for maximum compressive strength and then to determine the PEG4000 curing agent dosage to yield maximum strength. The entire work has been conducted in two phases. In the first phase the highest compaction factor corresponding to the maximum compressive strength was determined and then the effect of the curing agent at various proportions on the mechanical properties of the concrete has been investigated at the optimum superplasticizer dosage.

2. Materials and Methods

2.1. Materials

Cement used in the casting of the concrete samples was Ordinary Portland Cement of 43 grade confirming to IS 8112:1989 [34], manufactured by Jaypee cement. The sp. gravity, standard consistency, initial setting time and final setting time of cement were found as 3.15, 30%, 90 minutes and 165 minutes respectively. Locally available poorly graded coarse grained sand with fineness modulus of 3.01, specific gravity of 2.62 and water absorption of 0.5% was used in the current study. The coarse aggregate of maximum nominal size 10mm were obtained from a local quarry site. The sp. gravity and water absorption of coarse aggregates were 2.66 and 0.25% respectively. PCE based superplasticizer which is high range water reducer, was used for improving the workability of the concrete so that it may compact by its own weight. This can reduce the water requirement up to 25% to 30% and thereby helps in reducing the cement content for a required strength. PEG 4000 is used as a curing agent for making the concrete self-curing. The characteristics of the curing compound, as provided by the supplier, are given in table 1.

| S.N | Characteristic                          | Value      |
|-----|----------------------------------------|------------|
| 1   | Avg. Molecular Wt. (AMW)               | 3600-4400  |
| 2   | Avg. Hydroxyl No. (mg KOH/g)           | 25-32      |
| 3   | Density, g/cm³ @ 60°C                  | 1.0926     |
| 4   | Melting or Freezing Range (in °C)      | 53-59      |
| 5   | Water solubility at 20°C, % by weight | 66         |
| 6   | Viscosity at 100°C                     | 140.4      |

2.2. Mix Preparation

The concrete mix was designed as per IS 10262 - 2009 and IS 456-2000 [35], [36]. The conventional concrete has been manufactured using 10 mm nominal MSA. M30 grade of concrete has been adopted having a w/c ratio as 0.44. Later 0.8%, 1.0% and 1.2% by weight of cement dosage of superplasticizer, PCE was mixed in the sample, to make itself compacting. In the second study self-curing agent PEG4000 has been used in conjugation with PCE in ratio 1.2%, 1.4%, 1.6% and 1.8% by weight of cement. By analyzing all the parameters, design mix of M30 is been calculated as 1:1.43:2.37.

2.3. Sample Preparation

M30 grade concrete was developed with poorly graded sand and 10mm size coarse aggregates in the laboratory. A total 48 cubes of sides 0.15 m x 0.15 m x 0.15 m, 48 cylinders of dia. 0.15 m and ht. 0.3 m and 48 beams of size 0.5
m x 0.1 m x 0.1 m were cast and investigated for strength in compression, tension and flexure after one and four weeks of curing.

3. Results & Discussions

The entire investigation has been carried out in two phases. A total of 24 cubes, 24 cylinders and 24 beams were cast for the designed M30 grade concrete with a mix proportion of 1:1.43:2.37 in both the phases.

3.1. First Phase Investigation

In the first phase, optimum dosage of the PCE based superplasticizer (SP) has been determined for the maximum compressive strength. The superplasticizer was added to the mix at the rate of 0.8%, 1.0% and 1.2% by wt. of the cement. The effect of changing superplasticizer dosage has also been determined on the splitting tensile strength and flexural strength at 7 and 28 days of curing.

3.1.1. Workability and Compressive Strength

The workability of all the samples has been determined using the compaction factor test in accordance with IS: 1199-1959. PCE based superplasticizer has been used to enhance the workability. The superplasticizer has been added to the mix in the proportions of 0.8%, 1.0% and 1.2% by weight of cement. The compressive strength of all the 24 cube specimens have been determined at 7 and 28 days of curing using compression testing machine as per IS: 516-1959. Figure 1 (a) and (b) shows the effect of superplasticizer dosage on the workability and compressive strength of the mix at 7 and 28 days respectively.

![Fig. 1](image)

**Fig. 1** Workability and compressive strength variation with superplasticizer dosage at (a) 7 days (b) 28 days of testing

Figure 1 (a) and (b) clearly shows that the workability of the mix is increasing as the proportion of superplasticizer is increasing. However the compressive strength both at 7 and 28 days has increased only upto 1% superplasticizer dosage and then started decreasing. The compaction factor value of the mix at 0.8%, 1.0% and 1.2% of superplasticizer was obtained as 0.90, 0.96 and 0.97 respectively while it was only 0.78 for the conventional mix. This increase in the workability is due to the availability of more water in the mix which is because of the dispersion action of the superplasticizer that prevents the flocculation of the cement particles and thereby minimizing the entrapment of water in the mix. The compressive strength of the mix at 0.8%, 1.0% and 1.2% superplasticizer has increased as compared to the conventional mix by 1.1%, 4.8% and 1.4% at 7 days of testing and by 1.7%, 5.1% and 1% at 28 days of testing. The maximum compressive strength for both 7 and 28 days of testing has been obtained at 1% superplasticizer dosage and increase in strength has reduced at 1.2% dosage of superplasticizer. This might be
because of the reason that the cohesiveness of the mix gets reduced at higher superplasticizer dosage causing segregation in the mix and thereby reducing the compressive strength.

3.1.2. Splitting tensile strength and flexural strength

Splitting tensile strength test has been conducted on all the 24 cylindrical specimens of height 150mm and diameter 150 mm as per IS 5816: 1999 and IS: 516-1959 at 7 and 28 days of curing. The load was applied at a rate of 2kN/mm²/min and is increased till the failure of the specimen. Figure 2 (a) and (b) shows the test results of the splitting tensile strength and flexural strength respectively.

It is evident from Figure 2 (a) and (b) that the trend of the increase in the splitting tensile strength and flexural strength is similar to the compressive strength results. The splitting tensile strength of 1.87MPa, 2.10MPa, 2.56MPa and 2.42MPa was obtained at 7 days of testing and 2.18MPa, 2.26MPa, 2.93MPa and 2.85MPa was obtained at 28 days of testing for 0%, 0.8%, 1.0% and 1.2% superplasticizer dosage respectively. Similarly flexural strength of 3.35MPa, 3.41MPa, 3.76MPa and 3.53MPa at 7 days and 4.75MPa, 4.45MPa, 4.80MPa and 4.56MPa at 28 days of testing for 0%, 0.8%, 1.0% and 1.2% superplasticizer dosage respectively. Similar to the compressive strength test results, the increase in splitting tensile strength and flexural strength first increased upto 1% superplasticizer dosage and then got reduced at 1.2% dosage. The reason for this is same as that for the compressive strength i.e. upto 1% the dispersion action of superplasticizer caused increase in strength and beyond 1% dosage the superplasticizer have reduced the cohesiveness of the concrete which resulted in a reduction in the increasing strength.

3.2. Second Phase Investigation

In the second phase testing, the optimum superplasticizer dosage, corresponding to the maximum increase in compressive strength, has been fixed at 1%. The Curing Agent (CA) i.e. PEG4000 has been added to the mix at the rate of 1.2%, 1.4%, 1.6% and 1.8% by weight of the cement. The effect of the CA has been investigated on the workability of the mix and on the compressive strength, splitting tensile strength and flexural strength at 7 and 28 days of testing.

3.2.1. Effect of curing agent on workability

The workability of all the samples has also been determined in the same manner as determined in the first phase. The dosage of PCE based superplasticizer has been fixed at 1% and the variation in the compaction factor values have been noted at all proportions of the curing agent i.e. from 1.2% to 1.8%. Figure 3 shows the effect of PEG4000 on workability of mix with 1% SP.
It is very clear from Figure 3 that the workability of the mix at 1% superplasticizer dosage is decreasing with the increase in the proportions of the curing agent. The compaction factor value at 1.2%, 1.4%, 1.6% and 1.8% curing agent was obtained as 0.95, 0.95, 0.94 and 0.91 respectively.

3.2.2. Effect of curing agent on Compressive Strength

The compressive strength of all the samples of second phase investigation was measured using compression testing machine as per IS: 516-1959. The compressive strength of all the 24 cube specimens having CA in the proportion of 1.2%, 1.4%, 1.6% and 1.8% has been determined at 7 and 28 days of curing. The proportion of SP has been fixed at 1% in all the samples. Figure 4 shows the effect of curing agent dosage on the compressive strength of the mix at 7 and 28 days of testing respectively.

From Figure 4 it is evident that the compressive strength of the self-compacting concrete with curing agent was less as compared to the normal water cured conventional concrete up to 1.4% proportion addition of curing agent both at 7 days and 28 days of testing. Compressive strength of 26.44MPa, 25.33MPa, 26.81MPa, 28.59MPa, and 27.4MPa at 7 days and 39.33MPa, 36.07MPa, 36.74MPa, 39.77MPa and 37.85MPa at 28 days for 1.2%, 1.4%, 1.6% and 1.8% of curing agent proportion.
3.2.3. Effect of curing agent on splitting tensile and flexural strength

Cylindrical specimens have been tested at 7 and 28 days as per the provisions given in IS: 516-1959 and IS: 5816-1999 for getting the splitting tensile strength and beam specimens have been tested at 7 and 28 days as per the provisions of IS :516-1959 for getting the flexural strength. Splitting tensile strength test was performed on compression testing machine whereas the flexural strength test was performed on universal testing machine using three point load method. Figure 5 (a) and (b) represent the results of the testing for splitting tensile strength and flexural strength respectively.

![Fig. 5 Effect of curing agent dosage on (a) splitting tensile strength (b) flexural strength](image)

It is evident from Figure 5 (a) and (b) that the curing agent has almost similar impact on the tensile and flexural strength of developed concrete both at 7 and 28 days of testing. The splitting tensile strength at 1% fixed SP dosage and 1.2%, 1.4%, 1.6% and 1.8% curing agent dosage was obtained as 2.73MPa, 2.42MPa, 2.61MPa, 2.99MPa, 2.92MPa and 3.91MPa, 2.89MPa, 3.13MPa, 3.98MPa, 3.65MPa at 7 and 28 days respectively. Similarly, the flexural strength was obtained as 3.35MPa, 3.25MPa, 3.4MPa, 3.9MPa, 4.75MPa, 4.65MPa at 7 and 28 days respectively. In both the cases the strength increased on increasing the dosage of curing agent and maximum strength was achieved at 1.6% and thereafter strength started decreasing. PEG4000 cured specimens attains the strength similar to the water cured concrete at 1.6% dosage. Strength of the curing agent incorporated concrete improved due to the reason that PEG4000 curing compound has hydrophilic terminal groups that attach itself with the film of water and decreases the dehydration of water from the concrete surface and thereby indirectly helping in developing the strength.

4. Conclusions

The characteristics of design mix concrete strength and workability were studied with use of 10mm size course aggregate with PCE based superplasticizer and PEG based moisture retaining agents. The optimum dosage of the PCE based superplasticizer and PEG4000 curing agent for the maximum strength of concrete has been determined. The following conclusions can be drawn from the current investigation:

- The strength and workability of the concrete in compression, tension and flexure found better by addition of 1% PCE based superplasticizer. The early gain of strength has been found higher in comparison to 28days strength.
• The strength of the concrete in compression, tension and flexure was found better by addition of 1% PCE based superplasticizer and 1.6% PEG based water retaining agent. Though workability reduced by addition of PEG based water retaining agent, early gain of strength has been found higher in comparison to 28 days strength.

Based on the present study, it is preferred that PEG based water retaining agent should not be used alone as it reduces the workability of the sample and in turn creates a harsh sample of concrete.

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