Structural behavior of self-curing concrete with partial replacement of coarse aggregates with fly ash pellets

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Abstract

As we are in the world to conserve water for our daily needs, the present technologies have to be optimized in a feasible way, especially to one of the process curing in construction field. Thus, indeed there is an immediate need to do research on water used for curing process on concrete. Curing is one of the significant process for the concrete to have sufficient moisture content particularly at early stages of concreting in order to enhance the property of the concrete. It also plays a major role in concrete by developing pore structure and microstructure thus enhances its performance and durability. By considering these importance’s about curing and also to minimize the water for curing of concrete, a study has been conducted on concrete with the help of Polyethylene Glycol-400 (PEG-400) a water soluble self-curing agent to reduce the usage of water for curing. The present study also emphasis the use of fly ash pellets (FAP) prepared from the waste fly ash as coarse aggregate partially. The trail mix of concrete is proportioned replacing coarse aggregate by 10%, 15%, 20%, 25% and 30% with FAP and the compressive strength of the concrete were determined and found the optimum percentage replacement of coarse aggregate with FAP is at 25% resulting maximum compressive strength. The mechanical properties of concrete using water-soluble Polyethylene Glycol (PEG 400) have been found and also identified the optimum dosage to achieve maximum mechanical properties of the concrete. The increase in water retention capacity in the concrete and reducing the water evaporation in curing process can be done by using self-curing agent and it will absorb the water from the atmosphere thus saves water in the curing process compare to conventional concrete. The concrete mechanical properties containing self-curing agent are studied at various percentage such as 0.5, 0.7, 0.75, 0.8 and 1.0 added by weight of cement and compared with those of conventionally cured concrete. From the investigation it has been concluded that optimum dosage of PEG-400 for maximum mechanical property of M25 grade of concrete containing 25% of fly ash pellets as coarse aggregate is at the percentage of 0.75 by weight of cement.

Keywords: Mechanical properties of concrete, fly ash pellets, PEG, self-curing concrete.

1. Introduction:

From the last two decades, concrete technology gets popularized in the construction industry. Also recently internal curing of concrete evolved and started practicing at site. Curing process in the concrete is must because it helps in developing the hardness and strength of the concrete by ensuring...
the effective hydration process in the cement which binds all the ingredients of the concrete which enhances the concrete performance and durability.[1] American Concrete Institute (ACI) defines internal curing as “supplying water throughout a freshly placed cementitious mixture using reservoirs, via pre-wetted lightweight aggregates, that readily release water as needed for hydration or to replace moisture lost through evaporation or self-desiccation.”

At practice in construction site proper curing of concrete cannot be achieved because of the following reasons such as environmental condition, poor quality of water and poor workmanship. Also it has been found that the water content required for conventional concrete curing for 1 cubic meter concrete is 3m³. Many researches have done to identify effective self-curing agent to solve those water problems and to save water in the curing process. And many researchers were keen to identify the self-curing agent to give solution for improper curing problem and found self-curing agents [2]. Polyethylene-glycol is one of the self-curing agents which minimize the evaporation of water from the concrete by reducing the surface tension of the water and leads to enhance the durability of the concrete. Concrete incorporating self-curing agents for curing process will set a new trend in the construction industry all over the world in the upcoming years [3].Therefore the self-curing agent may be recommended for curing process in concrete since it plays a vital role in less consumption of water and gives benefit to the environment.

1.1. Self-curing
Internal curing states that refers to the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing water as per ACI-308 code. “Self–curing is well known for internal curing of concrete and it can be achieved by addition of chemical agent. These chemical agents will reduce the evaporation of water and retains the capacity of concrete [4]. Self-curing agents are made with water soluble polymers and it leads to play the major role by developing pore structure and microstructure in the concrete which enhance the performance and durability of the concrete. The internal curing method of concrete is discussed below

- Curing by using saturated porous light weight aggregate to have enough source internally to supply water for hydration of cement.

![Figure 1. Curing of concrete in conventional method versus internal Curing](image)

Paraffin Wax, Polyvinyl alcohol, Polyethylene glycol, SAP are some of the self curing agents available in the market. In this study optimum dosage of PEG-400 required to achieve the strength
properties without adding any mineral or chemical admixtures and the effect of self-curing agent in concrete were investigated [5].

1.2. Principle of polyethelyn glycol (PEG)-400
Polyethylene glycol (PEG) has the general formula H(OCH₂CH₂)nOH, as n denotes the average number of repeating ox ethylene groups typically from 4 to about 180 and it is a condensation polymer of ethylene oxide and water [6]. PEG has the property of non-volatile, non-toxic, water-soluble, neutral, non-irritating, lubricating, and odourless. Once PEG-400 self-curing agent is added to concrete it will react with water in the concrete and forms hydrogen bond. During hydration process the water molecules are attracted by self-curing agent leads to increase in water retention capacity and reduce the water evaporation from concrete [7].

1.3. Advantages of self-curing concrete
- Increases mortar strength
- Reduces autogenously cracking
- Reduces permeability
- Provides greater durability
- Resistance against the corrosive actions of salts and chemicals and abrasion will be improved
- Water scarcity, Labour cost is high, Water contains high fluoride content, Inaccessible structures in difficult terrains.

1.4. Objectives of study
The objective of the investigation are discussed below
- Physical property of the concrete ingredients is to be determined.
- The optimum replacement of coarse aggregate with fly ash pellets for maximum compressive strength is to be determined.
- The mechanical properties of concrete using water soluble Polyethylene Glycol as self-curing agent at various percentage additions is to be determined with 25% of fly ash pellets as coarse aggregate.
- To study the workability property of concrete by slump cone test with various percentage addition of PEG-400.
- Optimum dosage of PEG-400 to be added in the concrete for maximum strength is to be determined.
- Comparison of mechanical strength properties results of the self-curing concrete with conventional concrete is to be analyzed.

2. Material properties
The material specifications of concrete ingredients such as fly ash pellets, fine aggregate, cement coarse aggregate, fly ash pellets and Polyethylene glycol(PEG) -400 are determined in the laboratory and it is discussed in the table 1.
Table 1. Physical properties of concrete ingredients

| Material       | Property                      | Value      |
|----------------|-------------------------------|------------|
| 1. Cement      | Type                          | OPC        |
|                | Grade                         | 43 Grade   |
|                | Relative density              | 3.12       |
|                | Fineness modulus              | 3.43       |
|                | Consistency                   | 32%        |
|                | Initial setting time          | 32 min     |
| 2. Fine Aggregate (M-Sand) | Specific Gravity              | 2.60       |
|                | Fineness Modulus              | 2.60       |
|                | Dry Density                   | 1706 kg/m³ |
| 3. Coarse Aggregate | Specific Gravity              | 2.80       |
|                | Fineness Modulus              | 7.07       |
|                | Dry Density                   | 1659 kg/m³ |
| 4. Fly ash pellets | Specific gravity              | 2.12       |
|                | Water absorption              | 14.4%      |
| 5. PEG-400     | Specific gravity              | 1.12       |

3. Design mix proportion

Design mix proportion for the M25 grade concrete for the study is determined as per the guide lines of IS 10262:2009 [8]. Also the mix design after determination of optimum replacement of coarse aggregate by fly ash pellets in concrete to have maximum compressive strength is discussed in the table 2.

Table 2. Concrete material quantities for one meter cube

| Material               | Quantity |
|------------------------|----------|
| Cement                 | 420 kg   |
| Coarse aggregates (20 mm size) | 782.65 kg |
| Fine Aggregate         | 723 kg   |
| Fly ash pellets        | 169.5 kg |
| Water content          | 229 kg   |

The mix proportions by weight (C: FA: CA: W: FAP) = 1: 1.72: 1.86: 0.46: 0.4

Table 3 shows mix proportions of ingredients used in the study with different proportions of PEG-400 for 1 m³ of concrete and table 4 describes the number of specimen cast for the study with respect to the percentage of variation of PEG-400.
Table 3. Design mix proportions with incorporating various PEG%

| PEG- 400 % | PEG | Cement | FA | CA | FAP |
|------------|-----|--------|----|----|-----|
| 0.0        | 0.0 | 420    | 723| 782.62 | 169.5|
| 0.5        | 2.1 | 420    | 723| 782.65 | 169.5|
| 0.7        | 2.94| 420    | 723| 782.65 | 169.5|
| 0.75       | 3.15| 420    | 723| 782.65 | 169.5|
| 0.8        | 3.36| 420    | 723| 782.65 | 169.5|
| 1          | 4.2 | 420    | 723| 782.65 | 169.5|

Table 4. Number of specimens with different proportions of PEG-400

| Percentage of PEG-400 | 0.5% | 0.7% | 0.75% | 0.8% | 1% |
|-----------------------|------|------|-------|------|----|
| Compression strength  | 6    | 6    | 6     | 6    | 6  |
| Flexural tensile strength | 6  | 6   | 6     | 6    | 6  |
| Splitting tensile strength | 6  | 6   | 6     | 6    | 6  |
| Total number of concrete specimens cast for the study | 18  | 18  | 18    | 18   | 18 |

4. Experimental Investigations

4.1. Compressive strength of concrete along with fly ash pellets as coarse aggregate

Based on the mix proportion the trial mix for partial replacement of CA with FAP with different proportions was cast in the size 150 x150x150 mm of cube steel mould. The cubes cast are tested at 7th and 28th days of curing in the compression testing machine to determine compression strength of the concrete [9]. The table 5 discusses the maximum recorded values of the strength in compression of the concrete with respect to various percentage replacements of fly ash pellets and figure 2 shows the compression strength variation of the concrete with change in percentage of PEG tested after 7 days and 28 days and it is observed that at 25% replacement of coarse aggregate with fly ash pellets gives the maximum compressive strength [10].

Table 5 Compression strength of concrete using FAP

| FAP (%) replacing Coarse aggregate | Load (kN) | Compression strength 7th day (N/mm²) | Compression strength 28th day (N/mm²) |
|-----------------------------------|-----------|-------------------------------------|--------------------------------------|
| 0                                 | 475       | 21.11                               | 31.78                                |
| 10                                | 480       | 21.33                               | 31.80                                |
| 15                                | 484       | 21.51                               | 32.26                                |
| 20                                | 489       | 21.73                               | 32.49                                |
| 25                                | 496       | 22.04                               | 33.11                                |
| 30%                               | 473       | 21.02                               | 31.85                                |
4.2. Fresh concrete properties

The study was carried out with the design mix and after batching the workability of the mix was found by using slump cone test and the value of slump been recorded for various percentage of PEG. The table 6 shows the slump value with respect to change in percentage of PEG-400 and observed that the increase in percentage of PEG-400 in concrete leads to increase in slump value. Figure 3 is the pictorial representation of the slump value with respect to the respective PEG quantity.

Table 6. Workability slump values with respect to percentage of PEG

| % of PEG | Slump Value (mm) |
|----------|------------------|
| 0        | 75               |
| 0.5%     | 90               |
| 0.7%     | 100              |
| 0.75%    | 105              |
| 0.8%     | 110              |
| 1%       | 120              |

Figure 2. Concrete compression strength with fly ash pellets partially as coarse aggregate

Figure 3. Shows the Variation of the slump value with percentage variation of PEG
5. Concrete mechanical properties

5.1 Compression strength of concrete

The compression strength of concrete is determined with the cast concrete specimen of cubical size 150x150x150 mm. The maximum compression strength values at failure of concrete were recorded at 7th and 28th days of curing and it discussed in table 7 with respect to percentage variation of PEG and figure 4 describes the comparison of the compressive strength of concrete 7th and 28th days of curing with change in percentage of PEG.

| PEG-400(%) | Compression strength (N/mm$^2$) |
|------------|---------------------------------|
|            | 7th day                         | 28th day       |
| 0          | 22.04                           | 33.11          |
| 0.50       | 23.89                           | 34.37          |
| 0.70       | 24.70                           | 35.62          |
| 0.75       | 25.20                           | 35.95          |
| 0.80       | 24.95                           | 35.40          |
| 1.00       | 22.30                           | 34.80          |

Figure 4. Compression strength variation of concrete with respect PEG %

5.2. Splitting tensile strength

Splitting tensile strength of concrete are determined according to IS: 5816-1999 and it is carried out on cylindrical shape concrete specimen of 300 mm and 150 mm length and diameter respectively. The splitting tensile strength is the indirect method to find the concrete tensile strength and the strength determined from the compression testing machine. The values of the splitting tensile strength of the concrete is described in the table 8 and figure 5 displays the variation of splitting tensile strength of concrete the specimen with respect to change in percentage of PEG.

The tensile stress magnitude $F_{st}$ is determined by the formula
\[ F_{st} = \frac{2 \times P}{\pi \times D \times L} \]

Where,
- \( F_{st} \) = Splitting tensile strength of concrete
- \( P \) = Maximum Compressive load
- \( D \) = Diameter of the specimen
- \( L \) = Length of the specimen

### Table 8 Splitting tensile strength of the concrete at 7th and 28th day of curing

| PEG-400(%) | Splitting tensile strength (N/mm²) |
|-----------|-----------------------------------|
|           | 7th day | 28th day |
| 0.00      | 1.65    | 2.07     |
| 0.50      | 1.78    | 2.15     |
| 0.70      | 1.83    | 2.30     |
| 0.75      | 1.87    | 2.45     |
| 0.80      | 1.85    | 2.35     |
| 1.00      | 1.76    | 2.20     |

### Figure 5. Splitting tensile strength variation of concrete with respect PEG %

5.3. Flexural strength

The flexural strength of the concrete is determined by two-point load method as shown in the figure 9 as per IS: 516-1959. The flexural strength is determined in beams of dimension 100x100x500 mm. The load was applied on the beam without any vibration and was increased till concrete specimen gets failure. The maximum load applied on the concrete specimen at the failure was recorded. The values are maximum load are discussed in the table 9 and figure 6 displays the variation of flexural strength of concrete specimen with respect to change in percentage of PEG.
Figure 6. Show the experimental set up to determine flexural strength of concrete

Table 9. Flexural strength of concrete at 7th and 28th day of curing

| PEG-400 (%) | Flexural strength (N/mm²) |
|-------------|---------------------------|
|             | 7th day | 28th day |
| 0.00        | 3.2     | 4.1      |
| 0.50        | 3.4     | 4.4      |
| 0.70        | 4.2     | 4.8      |
| 0.75        | 4.6     | 5.2      |
| 0.80        | 4.4     | 5.0      |
| 1.00        | 3.8     | 4.6      |

Figure 7. Variation of flexural strength of concrete with respect PEG %

6. Discussions and conclusion
Experiments have been conducted to obtain mechanical properties such as compression strength, splitting tensile strength and flexural strength using various proportions of polyethelyn glycol and the effect of PEG as self-curing agent was observed in concrete when coarse aggregate is partially replaced by fly ash pellets with 25%. PEG-400 as self-curing agent in the study added to the weight of the cement in the concrete containing 25% of fly ash pellets instead of coarse aggregate has following conclusion:
The mechanical strength properties of the concrete increases with increase in the percentage of PEG up to 0.75% addition by weight of cement and attain the maximum strength.

The workability of the concrete measured with slump cone test increases with rise in the percentage of PEG in the concrete mix containing 25% of fly ash pellets as coarse aggregate.

The dosage of PEG-400 to be added in concrete by weight of cement is optimized for maximum compression strength, splitting tensile strength and flexural strength and the value recorded is 0.75% for M25 grade of concrete.

The use of PEG-400 reduces the water content for curing compared to nominal conventional concrete and also concrete with self-curing agent results in effective hydration under normal environmental condition.

The results of compression strength, splitting tensile strength and flexural strength of the self-curing concrete at the 0.75% of PEG in concrete shows increase in the strength of 6.4%, 2% and 8% respectively after 28 days curing when compared to conventional concrete.

The weight of the concrete was found to be reduced around 4.3% when compared to conventional concrete, because of partial replacement of coarse aggregate with fly ash pellets by 25%.

The fly ash pellets has less density compared to coarse aggregate hence it will reduce the self-weight of structural building which can adopt for high rise building, buildings in earthquake zones and water scarcity areas.

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