Compressive Strength and Water Absorption Behavior of Self-Curing Fiber Reinforced Concrete

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Abstract. Self-curing (internal curing) of concrete using shrinkage reducing admixture, super-absorbent polymers, and pre-saturated lightweight aggregates are established methods to prevent autogenous shrinkage and self-desiccation. However, using polypropylene fiber addition (PPF), that provides better control of plastic settlement and plastic shrinkage cracking are not found in the literature. This research is carried out to compare concrete with the addition of chemical shrinkage reducing admixture named polyethylene-glycol (PEG 400) with and without polypropylene fibers (PPF). The self-curing fiber reinforced concrete of 30 MPa strength, made of 1.5% PEG400 by weight of cement, and with or without 0.5% PPF by volume of fractions were prepared. The mixes were either exposed to air curing in room temperature or in a controlled temperature of 32°C. The compressive strength and water absorption behaviors are monitored. It was found that the use of PEG400 improved the workability but not the strength, while the addition of PPF has less effect on workability but reduces the strength. These results give better understanding PEG and PPF concrete to the industry.

1. Introduction

The construction industry uses up a huge amount of water for concrete curing. In the future, construction system will have to come up with other options for concrete curing, not only for water sustainability but also to encourage construction driven activities at regions with a shortage of water. Concrete curing is the procedure to reduce the loss of moisture due to hydration of cement in concrete. Hydration occurs during the production or after the placement of the concrete in position, which results in the provision of time for the processes of hydration to take place [1]. Curing must be done within a reasonable time-frame as it has a major effect on the concrete properties, namely the increase in strength, resistance to abrasion, freezing and thawing effects, water tightness, and durability [2-3].

In the conventional method, curing is carried out after concrete is de-molded. Water curing is the most effective technique in comparison to self-curing, membrane curing, dry air curing and wrapped curing techniques. However conventional water curing has limited applicability on construction site, especially for columns and inaccessible areas especially in high-rise buildings [3]. To achieve cement hydration effectively, the technique being utilized to increase the moisture in concrete and as well the reduction of self-desiccation is called self-curing or internal curing. Self-curing concrete is a concrete that can cure itself by retaining its moisture content [4].

A concrete can be self-cured by adding curing admixtures or by the application of curing compounds. The American Concrete Institute [5] code states that “internal curing 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”. Conventionally, concrete curing refers to the condition whereby the concrete is constantly saturated by absorbing moisture where curing happens from the outside to inside. On the
other hand, self-curing concrete is allowing curing to happen ‘from the inside to outside’ by the internal reservoirs created. To this point, the use of polyethylene glycol (PEG) as the admixture helps to reduce evaporation of water from the surface of concrete and helps in water retention that is consistently needed in the concrete. Besides PEG, several researchers have proposed the use of polyglycol products in concrete mixes as self-curing agent [4, 6], while others used saturated lightweight aggregates to provide ‘internal’ curing for concrete [7, 8]. However, the addition of polyethylene glycol by weight of cement will reduce the water evaporation from concrete, and hence increases the water retention capacity of the concrete [9]. Therefore, this research was carried out to determine the effectiveness of polyethylene glycol (PEG400) with and without polypropylene fiber (PPF) on strength and water retention of self-curing fiber reinforced concrete. Hopefully, self-curing concrete can be enhanced with the addition of PPF and that will control the temperature and the movement of moisture in the concrete. Due to the help of moisture stored in the concrete, hydration of cement will be more effective and will reduce self-desiccation and prevent surface cracking that occurs due to early shrinkage [10, 11].

2. Experimental Programme

2.1. Materials
Materials used to produce self-curing concrete are cement, fine and coarse aggregates, polyethylene glycol (PEG400), polypropylene fiber (PPF) and water. These materials are carefully chosen according to codes of practices appropriate for all the materials. The specimens are prepared using Type II Portland cement composite that are locally available according to ASTM C150 [12]. The aggregates are in saturated surface dry condition. The maximum size of the coarse aggregate is 10 mm. The specific gravity of course aggregates is 2.7 and 2.65 for the fine aggregates. The polyethylene glycol (PEG400) characteristics as produced by the manufacturer indicated in Table 1 is used as a self-curing agent for water retention. Polypropylene fibers (PPF) are produced from propylene gas and are thermoplastics. It is manufactured in big scale and is commercially known as Forta Ferro and the properties are presented in Table 2.

| Type       | Molecular weight | Viscosity range | Maximum solubility at 20°C (mass fraction %) | Functional group |
|------------|------------------|-----------------|--------------------------------------------|------------------|
| Synthetic  | 400              | 6.8-8.0         | 100                                        | Hydroxyl Ether   |

| Table 2. Properties of polypropylene fibers (PPF) |
|-----------------------------------------------|
| Length (mm) | 38        |
| Specific gravity (g/cm³) | 0.91     |
| Tensile strength (MPa)    | 650      |
| Density (kg/m³)           | 910      |

2.2. Mix proportions
Three different concrete mixtures are prepared in this research. The mix proportion of self-curing fiber reinforced concrete specimens is based on grade 30 concrete. The amount of material used for self-curing concrete batches per meter cube is given in Table 3. A constant percentage of polyethylene glycol (PEG 400) and polypropylene fiber (PPF) are added, which are 1.5% and 0.5% respectively.
Table 3. Mix proportion (kg/m$^3$)

| Concrete mixes | Cement | PPF | PEG (400) | Water | Aggregates | w/c Ratio |
|----------------|--------|-----|----------|-------|------------|-----------|
| Mix 1 (Ref)    | 400    | -   | -        | 180   | 1215       | 655       | 0.45  |
| Mix 2 (+1.5%PEG)| 400    | -   | 6 (1.5%) | 174   | 1215       | 655       | 0.45  |
| Mix 3 (+0.5% PPF & 1.5%PEG) | 400 | 4.55 (0.5%) | 6 (1.5%) | 174 | 1215 | 655 | 0.45 |

2.3. Experimental procedure
Mixing is made in a towable concrete mixer. The dry constituents (including PPF) are mixed for 2 min to ensure homogeneous mix then water was added gradually until finished. In case of self-curing concrete, the polyethylene-glycol (PEG400) was mixed with water before adding to the mixture. After mixing, the concrete mixtures are placed in 100 mm and 150 mm cubic molds and kept in the laboratory conditions for 24 hours. Then, the samples are de-molded and exposed for 28 days to three curing conditions; (1) water curing, (2) kept in the air with relative humidity of 65°C and 32°C, and (3) exposed at room temperature.

The workability of concrete is measured by the slump test according to BS 1881:102[13]. The compression test is according to BS 1881:116[14] at the ages of 7, 14 and 28 days. The sorptivity test is carried out according to ASTM C1585[15] to measure the rate of water absorption of concrete, by determining the increment in the weight of the specimen as water being absorbed through one surface only. Initial surface absorption test (ISAT) measures the water flow rate that penetrates into the concrete per unit area at an applied head and at an interval that has been stated from the beginning of the test. ISET test is conducted by applying 200mm head of pressure to model heavy rain in Malaysia based on BS 1881: 208[16]. The rate at which water enters the concrete pores is controlled by absorption caused by a capillary rise for unsaturated concrete.

3. Results and Discussion

3.1. Workability

The workability of different concrete mixes is shown in Figure 1. This revealed an increase in the workability with an addition of PEG400 and slight decrease with the addition of PPF. The workability of self-curing concrete made of PEG 400 (mix 2) increases by 50%, while the self-curing concrete made of PEG 400 and PPF (mix 3) increases by 30% compared to the control specimen (mix 1). The workability increases are expected because of the availability of additional internal water when PEG 400 was added[17]. On the other hand, the addition of PPF contributes to absorption of additional water from PEG and results in lower of workability than the mix 2.

![Figure 1. Height of Slump with addition of polyethylene glycol (PEG 400) and polymer fiber](image-url)
3.2. Compressive Strength

All compressive strength results for the three concrete mixes at different curing conditions are tabulated in Table 4. Mix 1 shows that different curing conditions did not significantly influence the strength of the concrete. Similarly, Mix 2 also shows insignificant different of strength at both curing conditions, that proof the addition of PEG did not influence the strength of concrete even though it increased the workability but this is contradicting to Slatnick et al. [18] which probably due to different percentages used. On the other hand, the addition of PPF reduced the strength of control concrete by 10%. The pore and weaker bond between PPF and other concrete materials are the main contributors to the strength reduction.

### Table 4. Compressive strength (MPa)

| Concrete mixes                        | Curing conditions | 7 days | 14 days | 28 days |
|---------------------------------------|-------------------|--------|---------|---------|
| Mix 1 (Plain concrete)                |                   |        |         |         |
| (M1. W.C)                             |                   | 24.75  | 29.32   | 28.19   |
| (M1. R.T)                             |                   | 23.98  | 27.25   | 30.83   |
| (M1. 32°C)                            |                   | 25.35  | 27.26   | 28.2    |
| Mix 2 (+1.5PEG)                       |                   |        |         |         |
| (M2. R.T)                             |                   | 23.76  | 27.16   | 29.88   |
| (M2. 32°C)                            |                   | 22.05  | 27.06   | 27.54   |
| Mix 3 (+1.5% PEG & 0.5% PPF)          |                   |        |         |         |
| (M3. R.T)                             |                   | 20.83  | 22.74   | 25.90   |
| (M2. 32°C)                            |                   | 22.14  | 24.64   | 24.75   |

Note: a Water cure, b Room temperature, c Controlled temperature.

3.3. Sorptivity

The initial and secondary sorptivity results at different curing conditions up to 28 days are presented in Table 5. The lowest initial absorption is obtained from control specimens exposed to water curing (M1, W.C.), which is 0.0274mm/s$^{0.5}$ and the highest initial absorption is obtained from control specimens exposed to control temperature (M1, 32°C) of 0.0448mm/s$^{0.5}$. Initial sorptivity of M2 in both room and control temperatures are lower by 30% and 16% than the control mix. A similar observation was made on M3 with 15% and 20% lower than the control. However, at secondary stage, both M2 and M3 gained much more absorption than the control sample in both curing conditions. These show that addition of PEG will increase the rate of water absorption i.e. less water resistance at later age of the concrete causing less dense composite and thus lower strength measured when mixed with PEG.

### Table 5. Sorptivity at initial and secondary stages (mm/s$^{0.5}$)

| Concrete mixes                        | Curing conditions | Initial absorption | Secondary absorption |
|---------------------------------------|-------------------|--------------------|----------------------|
| Mix 1 (Plain concrete)                |                   |                    |                      |
| (M1. W.C)                             |                   | 0.0274             | 0.0075               |
| (M1. R.T)                             |                   | 0.0419             | 0.0033               |
| (M1. 32°C)                            |                   | 0.0448             | 0.0029               |
| Mix 2 (+1.5PEG)                       |                   |                    |                      |
| (M2. R.T)                             |                   | 0.0295             | 0.0090               |
| (M2. 32°C)                            |                   | 0.0375             | 0.0033               |
| Mix 3 (+1.5% PEG & 0.5% PPF)          |                   |                    |                      |
| (M3. R.T)                             |                   | 0.0356             | 0.0056               |
| (M2. 32°C)                            |                   | 0.0354             | 0.0055               |

Note: a Water cure, b Room temperature, c Controlled temperature.
3.4. Initial surface absorption test (ISAT)

Generally, the purpose of ISAT is almost similar to the sorptivity, the difference is that sorptivity is using capillary action when water is penetrated into a concrete specimen using a head pressure of 200 mm in size. The results of ISAT for all concrete specimens are tabulated in Table 6. As expected, the control specimens at room and control temperatures show a higher rate of absorption than water cured, as shown in Figure 7. The specimens at room temperature (M1, R.T.) increased the rate of absorption by 12% at 10 min and 7% for both 30 min and 60 min compared to water curing specimens (M1, W.C.). While, M2 in control temperature (M2, 32°C) increased the rate of absorption by 18%, 15% and 29% at 10 min, 30 min, and 60 min, respectively than water curing specimens (M1, W.C.). This happened due to a lower porosity of water curing specimens than the specimen at room and controlled temperature.

Addition of 1.5% PEG 400 to the self-curing concrete specimens at room temperature (M2, R.T.) reduced the rate of absorption by 23%, 15% and 4% at 10 min, 30 min, and 60 min respectively compared to control concrete of the same curing conditions (M1, R.T.). Similarly, M2, 32°C specimen attained lower absorption by 21.5%, 18.5% and 20% at 10 min, 30 min, and 60 min respectively than control specimens (M1, 32 °C). At the same curing conditions, specimens with PEG 400 reduced the absorption by 21%, while the plain concrete is by 12%, proofed that the earlier is more effective in water retention than water absorption.

From the results, it can be concluded that the absorption rate of all specimens decreased significantly from 0 min to 60 min. The result is reasonable as the absorption capacity of concrete depends on effective porosity. At 60 min, the porosity of concrete is mostly filled by water hence lower absorption capacity is measured. The additional of PEG400 to specimens of concrete reduces the absorption rate more than water curing specimens. However, the addition of PPF does increase the absorption rate higher than control and specimens without PPF.

Table 6. Initial surface absorption test (ml/m²s).

| Concrete mixes          | Curing conditions | 10 min | 30 min | 60 min |
|-------------------------|------------------|--------|--------|--------|
| Mix 1 (Plain concrete)  | (M1. W.C)        | 0.133  | 0.101  | 0.072  |
|                         | (M1. R.T)        | 0.151  | 0.109  | 0.077  |
|                         | (M1. 32°C)       | 0.163  | 0.119  | 0.101  |
| Mix 2 (+1.5PEG)         | (M2. R.T)        | 0.116  | 0.093  | 0.074  |
|                         | (M2. 32°C)       | 0.128  | 0.097  | 0.081  |
| Mix 3 (+1.5%PEG & 0.5%PPF) | (M3. R.T) | 0.200  | 0.153  | 0.128  |
|                         | (M3. 32°C)       | 0.228  | 0.125  | 0.105  |

Note: a Water cure; b Room temperature; c Controlled temperature

4. Conclusions

The performance of self-curing fiber reinforced concrete made of polyethylene glycol 400 (PEG 400) as self-curing agent and polypropylene fibers (PPF) was investigated at three different curing conditions; water curing, room temperature and control temperature (32°C with a relative humidity of 65%). Based on the experimental results previously discussed, the following conclusions can be made:

- The use of polyethylene glycol 400 (PEG 400) as self-curing agent and polypropylene fibers (PPF) separately or in conjunction in concrete mixes increased the workability of concrete by 30-50% from to control concrete.
- The specimens contain PEG achieved same compressive strength to the control specimens at all curing condition. However, the addition of PPF shows slight reduction than the control and mix
with PEG only. The strength reduction is due to the smoother surface quality of the concrete containing PEG and PPF that subsequently increases the number of pores in the concrete.

- The absorption rate of all concrete specimens decreased significantly at 0 min to 60 min because the porosity of the concrete is reduces at later age. The sorptivity test of the same curing conditions show specimens with PEG reduced the absorption rate by 21%, while the water curing is by 12%. Similar observation made from ISET test, where the additional of PEG reduces the absorption rate more than control. While addition of PPF increased the absorption rate of the specimens higher than the control and specimens without PPF.

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