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Evaluating plastic shrinkage and permeability of polypropylene fiber reinforced concrete

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Abstract

Plastic concrete is susceptible to develop cracks due to shrinkage in dry and windy conditions. Addition of fibers could reduce propagation of this crack. On the other hand, permeability determines the durability properties of concrete. This study evaluated strength, plastic shrinkage and permeability (gas and water) of concrete incorporating 'polypropylene' fiber (aspect ratio 300) in various proportions (viz. 0.10%, 0.15%, 0.2%, 0.25% and 0.3%) by volume of concrete. Plane concrete samples were also prepared and tested for reference purpose. Inclusion of 0.1% fiber gave minor reduction (2%) in compressive strength while the tensile strength increased by 39% with same fiber content compared to the plain concrete. A significant reduction in crack generation, appearance period of first crack and crack area between plane concrete and fiber reinforced concretes was found. The experimental result with inclusion of 0.1–0.3% fiber in concrete indicated that plastic shrinkage cracks were reduced by 50–99% compared to the plain concrete. For reference concrete (without fiber), test within the high temperature and controlled humidity chamber gave higher crack width than the acceptable limit (3 mm) specified by the ACI 224. With the inclusion of 0.1% fiber reduced the crack width down to 1 mm and the trend was continued with the addition of more fibers. However, results showed that with the addition of polypropylene fiber both water and gas permeability coefficient was increased. Therefore, it is concluded that the fiber reinforced concrete would work better for plastic shrinkage susceptible structural elements (flat elements such as slab); however, it requires careful judgement while applying to a water retaining structures.

Keywords: Fiber reinforced concrete; Plastic shrinkage; Water permeability; Gas permeability; Polypropylene fiber

1. Introduction

Plain, unreinforced cement concrete is a brittle material with a low tensile strength capacity but strong in compression (Nilson et al., 2012; Nemati, 2013). The weaknesses sometimes limit its use. Another fundamental weakness of concrete is that cracks start to form as soon as concrete is placed and before it has properly hardened. These cracks are a major cause of weakness in concrete particularly in large onsite applications leading to subsequent fracture and failure and general lack of durability (Sivakumar and Santhanam, 2007). The weakness in tension can be overcome by the use of conventional reinforcement and to some extent by the inclusion of a sufficient volume of certain fibers (Ahmed et al., 2006).

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Plastic shrinkage is the contraction of the concrete due to water evaporation from the mixture. This causes the concrete to weaken and can lead to cracks, internal warping and external deflection (Ahmed et al., 2006; Sivakumar and Santhanam, 2007). Concrete shrinkage could be challenging during construction, especially for the flat structural elements for example the floors and slabs (Pietro, 2011). Three-dimensional volume changes in fresh concrete occur primarily due to rapid loss of surface bleed water on evaporation. These results in the rapid drawdown in pore water level, causing an increase in pore water pressure, which tends to bring the neighboring solid particles closer. All this leads to shrinking of cement paste; the restraint offered by aggregates leads to cracking on the surface of fresh concrete (Sivakumar and Santhanam, 2007). Plastic shrinkage cracks are typically observed in thin concrete elements with a high surface area to volume ratio (Rouhi et al., 2011). Fresh concrete is susceptible to plastic shrinkage cracking especially during hot, windy, and dry weather conditions (NRMCA, 2015). If the evaporation rate becomes significantly higher than bleeding rate, it can cause high tensile stresses to develop in the capillary pores in the surface zone of concrete that may be sufficient to exceed the tensile strength of concrete, especially at early ages (Pietro, 2011). In case of the surface cracks that develop as a result of plastic shrinkage remain unnoticed, they become channels for passage of external deteriorating agents and reduce long-term durability (Pietro, 2011). Precautions against plastic shrinkage cracking include preventing rapid drying of the surface of concrete and adopting good curing practices. Besides these, the use of fibers as a secondary reinforcing mechanism can help in mitigating the stresses developed upon drying (Ramujee, 2013). The addition of non-metallic fiber (polypropylene) has been reported to provide adequate tensile strength to concrete in addition to controlling shrinkage cracks (Sivakumar and Santhanam, 2007).

Permeability refers to the amount of water migration through concrete when the water is under pressure, and also to the ability of concrete to resist penetration of any substance, be it a liquid, gas, or chloride ion (Chen et al., 2001; Ahmed et al., 2006). This plays an important role in durability because it controls the rate of entry of moisture that may contain aggressive chemicals and the movement of water during heating or freezing (Desmettre and Charron, 2012). Therefore, higher the permeability lesser will be the durability (Miloud, 2005). Permeability of concrete is of interest also in relation to the water-tightness of liquid-retaining structures (Hoseini et al., 2009). The permeability of concrete is a function of the permeability of the paste (cement and water), and gradation of the aggregate, and the relative proportion of paste to aggregate (Roy, 2012). Decreased permeability improves concrete's resistance to re-saturation, sulfate and other chemical attack, and chloride ion penetration (Miloud, 2005).

A low-permeability concrete requires a low w/c ratio and adequate moist-curing (Yi et al., 2011). However, as is the case with water flowing through the porous medium, the internal pore structure of concrete is assumed to play an influential role on gas flow. Therefore, the size and volume of capillary pores and their continuity are important (Ahmed et al., 2006). These in turn are controlled primarily by water-cement ratio and degree of hydration. Microcracks present in concrete are also considered to offer additional passages for the flow of gas, resulting in an increased of gas permeability. In addition to the geometrical characteristic of the microstructure of concrete, moisture conditions in the pores are important with respect to the gas permeability of concrete. Free capillary water that will first evaporate by ordinary drying has a pronounced influence on the flow of gas in concrete. Water-saturated concrete has virtually zero permeability of gas when measured by a pressure-induced gas method. Gas permeability increases with the progressive drying of the concrete (Sugiyama et al., 1996).

The research experimentally deals with the effects of polypropylene fiber inclusion on two important properties of concrete viz. plastic shrinkage and permeability (both water and gas under pressure). Corresponding effect on concrete strengths (compressive and tensile) are measured and discussed in this paper.

2. Materials and methods

2.1. Materials

2.1.1. Cement

Ordinary Portland Cement with strength class 52.5 N was used. The percentage of clinker and gypsum in the cement was 95–100% and 0–5%, respectively while the specific gravity was found to be 3.15.

2.1.2. Superplasticizer

Retarding superplasticizer based on polycarboxylic ether was used as an admixture. This is commercially available in liquid form and dispensed into the concrete mixing water before adding it into the mix. Properties of admixture are given in Table 1.

2.1.3. Aggregate

Coarse sand was used as fine aggregate while crushed stone chips conforming to ASTM C33 was used as coarse aggregate. Both aggregates were obtained from Sylhet region of Bangladesh. Physical properties of aggregates

Table 1
Properties of superplasticizer.

Aspect	Light Brown liquid
Relative density	1.08 ± 0.01 at 25 °C
pH	⩾6
Chloride ion content	<0.2%
Expected water reduction, (%)	>20
Conforming standards	ASTM C-494, EN 934-2, IS 9103