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Effectiveness of chemical treatment on polypropylene fibers as reinforcement in pervious concrete

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HIGHLIGHTS

- Chemically treated fibers have shown higher bond strength with the concrete matrix.
- Fiber reinforcement did improve the compressive strength of pervious concrete.
- Fiber-matrix interface behavior in pervious concrete is characterized experimentally.
- The affected zone of each fiber in pervious concrete is less.

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ABSTRACT

Fiber reinforcement delays the crack generation and enhances the strength of the host matrix. However, the bonding mechanism between fiber and concrete matrix is controversial in literature and needs better explanation. Due to surface smoothness and inert chemical nature of commercially available fibers, several mechanical and chemical treatment techniques have been studied by researchers to increase the fiber-matrix bonding properties. The use of fibers in pervious concrete is even more challenging due to high porosity and insufficient fiber-matrix bonding interface. This study discusses the effect of chemical treatment on short polypropylene fibers and its uses in pervious concrete as reinforcement. The change in fiber surface due to the treatment is determined through fiber wettability test and Atomic Force Microscopy (AFM). Changes on the tensile strength of fibers by the treatment methods are also tabulated. Single fiber pullout tests are conducted to study the effect of the treatment type on fiber-cement interface properties. Treated fibers are then put into pervious concrete matrix for compressive and flexural strength tests. Chemical treatments are found to improve the surface roughness and cement matrix interface properties, as well as to enhance the overall strength of the fiber reinforced pervious concrete.

1. Introduction

Polypropylene fibers are widely used as reinforcement in concrete composites due to their superior properties over other fibers. Commercially available polypropylene fibers offer high melting point and better chemical stability than other fiber types such as steel or fiberglass fibers, and the cost is relatively less. These fibers are used as secondary concrete reinforcement to restrict the initiation and propagation of shrinkage cracks. However, being hydrophobic in nature, polypropylene fibers often result in poor bonding with the concrete composites.

By adding the polypropylene (PP) fibers to concrete, it is possible to improve the tensile strength of the concrete. Reinforcing PP fibers can improve the durability of the concrete matrix by increasing the ductility and absorbing energy when subjected to impact loads and external vibrations [1]. However, polypropylene chain structure is chemically inert, hydrophobic and has low surface energy. When mixing the PP fibers into the concrete mixture, the fibers will form clusters and the uniform distribution cannot be achieved. Clusters of fibers often trap considerable amount of air, which has an adverse effect on the mechanical properties of the fiber-reinforced concrete [2]. Therefore researchers have adopted several chemical treatment processes to increase its surface energy. Plasma treatment is one of the eco-friendly approaches to increase the surface energy of polypropylene fibers.

Zheng et al., [3] studied the use of relatively low-modulus polypropylene fibers (without any mechanical/chemical) treatment in concrete matrix. The results showed that there were no considerable improvements in the tensile strength. However, the

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flexural strength, toughness, and ductility in concrete were significantly improved. Concrete reinforced with collated and fibrillated polypropylene fibers at a relatively low volume fraction are usually used as secondary temperature shrinkage reinforcementing, crash barriers, slabs, overlays, and pavements. The fiber-concrete initial bonding can be affected by both the mechanical bonding properties of fiber and the static friction inherited by the fiber surface [4]. Chemical bonding between the fibers and the matrix are found to be weaker in comparison with the fiber's resistance to friction against the pull-out [5]. Also, most fiber deformation and degradation processes initiate local mechanical interactions between fiber and matrix, which leads to a redistribution of the load by the matrix. Fibers tend to arrest crack generation through the initial loading stages, and keeps increasing the required energy for crack propagation. Thus it provides an increment in the flexural strength. During the later stages of straining, the fibers redistribute the microcracking, thus increasing toughness and ductility.

The main disadvantage of using polypropylene fibers as a reinforcement is their non-polar nature [6], which prevents adhesion to concrete matrix. Several methodologies in literature have used shrinkage reducing admixtures, which help to increase compatibility of polypropylene fibers and limit crack width [7]. The key factor to obtain good mechanical properties for fiber reinforced concrete is the interfacial adhesion between the concrete matrix and the fiber [8,9]. Mechanical modifications, such as fibrillations and fiber indentation increase the bonding with cement matrix. Surface treatments can modify the fiber/concrete interface by roughening the fiber surface and altering surface polarity [10]. The modification of the surface chemistry and morphology through chemical treatment can increase the interfacial bond strength in comparison with the untreated PP fiber-concrete matrices.

Regarding techniques used in testing fiber reinforced concretes (FRC), many reports cite the improved static strength characteristics of such composite systems [11]. However, results of compression testing of fiber reinforced concrete reported by some researchers have shown conflicting information. Early reports, such as those by Hannat et al. [12], found that concrete without fiber reinforcement is stronger in compression compared to polypropylene fiber reinforced concrete. It was later reported by Fialova, et al. [13] that polypropylene fiber reinforced concrete (PFRC) reaches to a higher compressive strength after 28 days of cure time than that of plain concrete. Several researchers [14] in the FRC field explained that standard uniaxial compression testing should not be the only test method used to conclude on the mechanical properties of such composites. Other mechanical test methods, such as flexural strength tests should be conducted to determine the static strength characteristics of FRC composites.

In this work, the short polypropylene fibers were chemically treated to enhance the fiber-matrix interface properties and used in pervious concrete to study its effect on the compressive and flexural strength. First, the effect of chemical treatments on the PP fiber is discussed. Then fiber pullout tests were conducted on both treated and untreated fibers to study the change in fiber-cement matrix interface properties. Chemically treated fibers were then analyzed with Atomic Force Microscopy (AFM) for evaluating the enhancement of surface roughness. Both compressive and flexural strength tests were then carried out with cylinder and beam specimens, respectively, and results were reported.

2. Materials and methods

2.1. Properties of polypropylene fiber

ProCon-F-E polypropylene fibers, manufactured by Nycon have been used throughout the study. ProCon-F-E is a cost-effective fiber that provides plastic shrinkage and settlement crack control, increased impact resistance and residual strength. The physical properties of the polypropylene fiber are listed in Table 1.

2.2. Chemical treatment of polypropylene fibers

Polypropylene fibers are used for cement reinforcement in two ways [15]: (a) As a primary reinforcement, with 5–10% fiber content by volume. Polypropylene fibers are used as a mesh or fabric in such applications, which yields continuous reinforcement. (b) As a secondary reinforcement, with short fibers and lower content by volume (less than 0.3%).

Polypropylene fibers have a hydrophobic surface and it's modulus of elasticity is lower than that of cement matrix. As a matter of fact, it is assumed that there is no existence of physico-chemical adhesion bonding between polypropylene fibers and cement when they are mixed together. In this study, four different treatments are evaluated in terms of their effect on the mechanical properties of fiber reinforced pervious concrete.

1. Porofication treatment – the monofilament fibers were dipped in a Br_2+H_20 (10–11 ml/liter) solution for 24 h at 20 °C and then placed in an ammonia solution for 1 h at 40 °C. The fibers were washed with water and dried at room temperature. This treatment induces a rough and porous surface (hence called 'porofication') and increases the fiber surface area.
2. Treatment with surface-active agents (detergent) – the monofilament fibers were dipped in a solution of nonionic detergent (Triton X-100, 0.1% concentration) in water for 10 s, and dried at room temperature. This treatment was applied to enhance the wetting properties of the polypropylene fiber's surface, and intended to improve the fiber compatibility with the matrix.
3. Treatment with polyvinyl acetate (PVAC) – after the porofication treatment the monofilament fibers were dipped in a 5% PVAC solution in water for 10 s and dried at room temperature. This treatment was provided to achieve better adhesion between the polypropylene fibers and the cement matrix through a PVAC layer. The porofication treatment was carried out so that the PVAC coat on the fiber's surface would be homogeneous.
4. Sulphuric acid-dichromate treatment – the monofilament fibers were dipped into a bath of 10% sulphuric acid and sodium dichromate solution for 18 h at 50 °C and then washed with water and dried at room temperature. This treatment might cause asperity on the fiber surface, and may introduce a chemical reaction and bonding between the polypropylene fibers and the cement matrix.

2.2.1. Wettability of polypropylene fiber

Wettability of a solid surface is the capability of liquid to adhere to the surface and it is related to the molecular interaction characteristics of both solid and liquid phases. Researchers have adopted two processes to measure the wettability of polypropylene fibers,

Table 1
Physical properties of polypropylene fibers used.

Filament Diameter	0.03″ (0.76 mm)
Fiber length	0.75″ (19.00 mm)
Specific Gravity	0.91
Tensile Strength	44 ksi (300 MPa)
Flexural Modulus	700 ksi (4.90 GPa)
Melting Point	320 °F (160 °C)
Color	White
Alkali Resistance	Excellent
Corrosion Resistance	High