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Behavior of fiber reinforced concrete for controlling the rate of cracking in canal-lining

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HIGHLIGHTS

- Reduction in the rate of cracking in concrete canal-lining is aimed.
- Concrete reinforced with fibers (i.e. jute, nylon, and polypropylene) is examined.
- Mechanical properties, water absorption, and linear shrinkage are investigated.
- Plain concrete is taken as reference for comparison.
- A significant enhancement in considered properties is noticed.

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ABSTRACT

Seepage is a major water loss (20–30%) from the canal as compared to the other forms of water losses. Concrete is commonly used for canal-lining to reduce the seepage loss. Considerable seepage (15–20%) has been observed even in the cement–concrete conventional sections. The performance of canals decreases with an increase in the rate of cracking in concrete canal-lining. The rate of cracking in canal-lining can be reduced by improving the flexure, compressive, and splitting-tensile strengths of concrete. Out of these, splitting-tensile strength of concrete plays a vital role in controlling cracks. The use of fibers for characteristics improvement of concrete is very ancient. Natural fibers include many benefits, like low cost due to its abundance, least health hazards, and flexibility. The use of synthetic fibers as reinforcement in matrix has also attained intentness by reasons of its high strength, less water absorption, and low density in nature. The overall aim of the research program is to explore materials for better performance of canal-lining in terms of reduced water losses by controlling its rate of cracking due to alternate wetting and drying, and due to differential settlement, etc. The purpose of this work is to examine experimental behaviors of jute fiber reinforced concrete (JFRC), nylon fiber reinforced concrete (NFRC), and polypropylene fiber reinforced concrete (PPFRC) for controlling the rate of cracking in canal-lining. For this purpose, the mechanical properties (compressive, splitting-tensile, and flexure strengths, energies, and toughness indices), water absorption, and linear shrinkage of JFRC, NFRC, and PPFRC are determined experimentally as per ASTM standards. The properties of plain concrete (PC) are used as reference. The proportion of 1:3:1.5:0.7 (cement: sand: aggregate: water) is used for PC mix. The mixes of JFRC, NFRC, and PPFRC are manufactured by adding the jute fibers, nylon fibers, and polypropylene fibers, respectively, in the same mix design as that of PC. For production of each type of fiber reinforced composite (FRC), fibers having length of 50 mm are added in concrete by an amount of 5% (by mass of cement). A reduction in compressive properties, and an

Abbreviations: A, aggregate; C, cement; CCE, compressive cracked absorbed energy (MPa); CPE, compressive pre-crack absorbed energy (MPa); CS, compressive strength (MPa); CTE, compressive total absorbed energy (MPa); CTI, compressive toughness index (–); FCE, flexural cracked absorbed energy (kN·mm); FPE, flexural pre-crack absorbed energy (kN·mm); FRC, fiber reinforced concrete; FRCs, fiber reinforced concretes; FS, flexure strength (MPa); FTE, total flexural absorbed energy (kN·mm); FTI, flexural toughness index (–); JF, jute fibers; JFRC, jute fiber reinforced concrete; kN, kilo-Newton; LS, linear shrinkage (mm); mm, millimetre; MoR, modulus of rupture (MPa); MPa, mega Pascal; NF, nylon fibers; NFRC, nylon fiber reinforced concrete; PC, plain concrete; PPF, polypropylene fibers; PPFRC, polypropylene fiber reinforced concrete; S, sand; SCE, splitting-tensile cracked absorbed energy (kN·s); s, second; SPE, splitting-tensile pre-crack absorbed energy (kN·s); SS, splitting-tensile strength (MPa); STE, splitting-tensile total absorbed energy (kN·s); STI, splitting-tensile toughness index (–); WA, water absorption (%); W/C, water-cement; Δ, deflection (mm); Δ_o, deflection at the maximum load (mm); ε_o, strain at the maximum stress (–).

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improvement in splitting-tensile and flexural strengths, water absorption and linear shrinkage is exhibited by FRCs over that of PC. Among the tested FRCs, PPFRC shows better performance. This may ensure to control the rate of cracking in canal-lining, ultimately improving its performance.

1. Introduction

The movement of water in downward direction into soil or substratum from a source of supply like reservoir or irrigation channel is known as seepage [1]. Seepage (20–30%) is a major water loss from the canal as compared to the other forms of water losses [2,3]. Luthra [4] investigated the type and quantity of losses in canals. It was reported that, for unlined canals, the conveyance losses varied from 25% to 60%. Kraatz [5] found that an average of 17.5% loss of flow occurred as seepage per km of irrigation canals in western Greece. So, it becomes important to reduce this seepage loss for increasing the conveyance efficiency. Karad et al. [6] reported that, if lining was provided in minors, the seepage losses could be reduced by nearly 39%. Concrete is commonly used for canal-lining to reduce the seepage loss, because concrete materials are usually available in the vicinities of the local farmers [7]. Concrete lining structure is identical to thin plate in which cracking occurrence is frequent [8]. Kahlown and Kemper [9] and USBR [3] also reported the occurrence of considerable seepage (15–20%) even in the cement–concrete conventional sections. The better performance of concrete lining can help in reducing the water loss. The reasons accountable for those cracks comprise of thermal stress (temperature variation), external load, differential settlement of the foundation, etc. [10]. Cui et al. [11] conducted an analysis on the causes of cracks in concrete canal-lining. Factors, responsible for cracks, were classified on the basis of data collected. Also, the method of 3D contact nonlinear finite element was used for a sensitivity analysis on these factors. Based on outcomes, it was reported that the factors responsible for concrete cracks were external loads, temperature difference, irregular settlement of foundation, expansion deformation of foundation soil, and humidity, etc. Observed cracks in concrete canal-lining are shown in Fig. 1. The cracking of concrete canal-lining can be in various patterns e.g. diagonal cracking (Fig. 1a), concrete deterioration (Fig. 1b), and relatively parallel cracking w.r.t cross-sectional line of a canal (Fig. 1c). But in most cases, the crack in concrete canal-lining appears across the total depth of the section. The direction and length of the cracks also depend upon the different types of factors responsible for the cracking. The length of the cracks due to bending and shear stresses is higher than that of cracks due to other reasons. The deep cracks are usually larger in width. The reason behind such cracks may be the higher water absorption which results in higher rate of deterioration.

a b c

Fig. 1. Observed cracks in concrete canal-lining, a. diagonal cracking, b. concrete deterioration and c. relatively parallel cracking.

The properties, which can enhance the performance of concrete canal-lining, are compressive, tensile, and flexure strengths of concrete. Out of these, the tensile strength of concrete played a vital role in controlling cracks [12]. Many engineering/mechanical properties (like flexure strength, tensile strength, fatigue resistant strength, abrasion and thermal impact) of composites (cement paste, mortar and/or concrete) can be efficiently improved by introducing fibers in it [13–22]. Fibers in concrete act as "crack arrester" [23,24]. The impact resistance and mechanical properties of concrete could be improved by use of even a low proportion of natural fibers [25]. Merta and Tschegg [26] carried out an experimental investigation on fracture energy of concrete composites reinforced with natural fibers. It was found that the addition of natural fibers enhanced the fracture energy of composites. Joshi et al. [27] reported that, in most of the cases, natural fiber reinforced composites were environmentally superior to glass fiber reinforced composites. Artificial fiber reinforced concrete reduced the rate of cracking in canal-lining by enhancing its mechanical properties [28]. Wang et al. [29] conducted an experimental study on synthetic fiber reinforced cementitious composites. Three types of tests (i.e. compaction tension, splitting-tensile, and flexure tests) were performed to study the tensile properties of concrete composites reinforced with acrylic, nylon, and aramid fibers. It was concluded that the properties of concrete composites were greatly enhanced by the incorporation of artificial fibers. It had been investigated that the addition of jute fibers in cement composites had substantially increased the tensile and flexural strengths, and toughness [30]. It was investigated by different researchers that the jute fibers (i) acted as crack-arresters, (ii) absorbed a significant amount of energy after the occurrence of cracks, and (iii) carried a major portion of the tensile stress in the composite material [31–36]. Kundu et al. [37] investigated that jute fibers, rational high tensile strength of which varied from 250 to 300 MPa, were about seven times lighter than steel fibers (having tensile strength of approximately 400–1200 MPa [38]). Ramaswamy et al. [39] examined the tensile elongation ratios and tensile-breaking strength of jute fiber. Two conditions were considered i.e. natural air-dry state and an alkaline environment (by submerging in the solution of sodium hydroxide having pH value of 11 for 28 days). It was reported that jute fiber had quite high breaking tensile strength of 2260 kg/cm^2 in natural dry state. During the period of immersion in alkaline medium, the loss of strength varied from 5% to 32%. Chandar and Balaji [40] reported significant enhancement of 27%, 12%, and 44% in compressive, splitting-tensile, and flexural strengths, respectively, of concrete due to incorporation of jute fibers. Cool et al. [41] reported that nylon fibers exhibited good tenacity, toughness, and excellent elastic recovery. Nylon fiber reinforced concrete (NFRC) performed well under accelerated