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Use of glass and nylon fibers in concrete for controlling early age micro cracking in bridge decks

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HIGHLIGHTS

- Reduction in early age micro cracking in bridge deck is considered.
- Glass and nylon fiber reinforced concrete are investigated.
- Compressive, splitting-tensile and flexural behaviors are studied.
- Results are compared with that of plain concrete.
- A considerable improvement is observed.

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ABSTRACT

One of the major defects in concrete bridge decks are the formation of early age micro cracking which ultimately reduces its durability. The inclusion of fibers in concrete slabs has showed satisfactory performance with improved mechanical properties and reduced early age micro cracking (EAMC). The relative high compressive strength (CS), achieved by using high cement content, is the main cause of early age micro cracking in concrete. The low tensile strength (TS) also results in less resistance to early age cracking. Other factors causing EAMC include temperature rise, water content and shrinkage strain. The EAMC can be reduced by increasing CS and TS with use of economical materials other than cement. In this work, mechanical properties of glass fiber reinforced concrete (GFRC) and nylon fiber reinforced concrete (NFRC) are determined for the application of concrete bridge decks. The effectiveness of glass fibers (GF) and nylon fibers (NF) in concrete will be checked by comparing mechanical properties of GFRC and NFRC with that of plain concrete (PC). The mix design ratio of PC is 1:3.33:1.67 (cement:sand:aggregate) with a water cement ratio of 0.71. The GF and NF having a length of 50 mm and a fiber content of 5%, by mass of cement, are added in the concrete mixture for the production of GFRC and NFRC. Standard specimens are tested for determining compressive, splitting-tensile and flexural strengths of PC, GFRC and NFRC. Pre-crack energy absorption and toughness indices are also studied for different types of loadings i.e. compressive, splitting-tensile and flexural loadings. There is a decrease in compressive strength and an increase in splitting-tensile and flexural strengths of GFRC and NFRC compared to that of PC. Even though pre-crack energy absorption of GFRC and NFRC is less but their toughness indices are more than that of PC. Thus, GFRC and NFRC are suitable for reducing EAMC in bridge decks.

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1. Introduction

There are many defects in bridge decks like early age micro cracking (EAMC), crazing, spalling and surface erosion. The major defect in concrete bridge deck is EAMC [1–8]. EAMC are developed due to drying shrinkage, temperature rise, chemical reactions or any other cause by which concrete volume changes [9]. EAMC developed in recently constructed bridge deck is shown in Fig. 1. To identify the cause for EAMC in concrete bridge decks, many

Abbreviations: CS, compressive strength; C.P.E, compressive pre-crack energy absorption; C.C.E, compressive cracked energy absorption; C.E (Max. P), compressive energy absorption; C.T.I, compressive toughness index; EAMC, early age micro cracking; F.P.E, flexural pre-crack energy absorption; F.C.E, flexural cracked energy absorption; F.E (Max. P), flexural energy absorption; F.T.I, flexural toughness index; GF, glass fibers; GFRC, glass fiber reinforced concrete; MoR, modulus of rupture; NF, nylon fibers; NFRC, nylon fiber reinforced concrete; PC, plain concrete; STS, splitting-tensile strength; S.P.E, splitting-tensile pre-crack energy absorption; S.C.E, splitting-tensile energy absorption; S.E (Max. P), splitting-tensile energy absorption; S.T.I, splitting-tensile toughness index; TS, tensile strength.

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Fig. 1. EAMC developed in recently constructed bridge deck.

studies have been performed since 1980s [10–13]. Darwin et al. conducted a survey on bridge deck cracking [5]. Three types of bridge deck overlays were studied (i.e. monolithic, conventional overlay and silica fume overlay). It was reported that most of cracks developed at early age and then get increased with time. The cracks density in bridge deck increased with an increase in water content, cement content and total cement paste volume in concrete. The silica fume bridge deck had less cracks as compared to that of monolithic and conventional bridge decks, due to less evaporation before wet curing. Wright et al. investigated causes of early age cracking on concrete bridge deck expansion joint repair sections [8]. Based on literature review done by Wright et al., causes of bridge deck cracking were classified into three categories: concrete material properties, structural design and construction practice. Accordingly, to study concrete material properties in detail, experimental investigation on different mix design ratios for bridge deck concrete was performed. The commonly used mix design ratios i.e. 1:2.37:4.34 and 1:2.73:4.67 with water cement ratio of 0.43 and 0.44, respectively, were considered. It was concluded that the mix design having less cement content showed better performance against early age cracking. Krauss and Rogalla reported that concrete properties had major effect on bridge deck cracking [11]. The factors affecting EAMC in bridge decks of concrete are compressive strength, tensile strength and cement content [8,14]. The concrete bridge deck cracking increased with an increase in compressive strength, achieved by using high cement content [15]. On the other hand, it can be claimed that EAMC can be reduced with increased compressive strength by using low cement content. Qiao et al. reported that low tensile strength in bridge decks resulted in less resistance to early age cracking [16]. When tensile stresses in bridge deck increased from the tensile strength of concrete, the cracks would occur [17]. The tensile stress (produced in concrete) changes with time after it is being poured because more stress is required to crack the mature concrete [18]. The both compressive and tensile strengths (with little increase) can be utilized for the reduction of EAMC.

The mechanical properties can be improved by using artificial or natural fiber reinforced concrete. The addition of small discrete and uniformly distributed fibers in concrete acts as crack arrestor and improves its dynamic and static properties [19]. In 1940s, the Russians recognized the use of glass fiber reinforced concrete (GFRC) and then it was developed for years by Canada, USA and England [20]. The GFRC is a composite material made up of cement, sand, aggregate and small discrete glass fibers [21]. The increased durability of concrete using glass fibers is reported [19,22–27]. Shirish performed a parametric study on glass fiber reinforced concrete to increase its durability, thus ultimately reducing cracking [19]. The micro cracks were developed before the applied load. When load was applied, the micro cracks opened up and propagated which ultimately caused the macro cracks. The cylinders and beams were cast for compressive and flexural strength test with different mix design ratios. The control mix design ratio was 1:3.24:5.1 with w/c ratio of 0.50. The glass fiber was added at the rate of 0.025% by total volume of concrete. The compressive strength was increased by 10% and flexural strength was increased by 8% as compared to that of control mix. Qureshi and Ahmed performed an investigation on strength properties of GFRC with different mix design ratios [28]. The mix design ratio for plain concrete was 1:1.5:3 with w/c ratio of 0.60. The contents of glass fibers were 0, 0.5, 1, 1.5, 2, 2.5, 3 and 3.5% by weight of cement. The specimens were cast for compressive, flexural and splitting-tensile strengths. The optimum percentage of fiber content came out to be 1.5% by weight of cement. The compressive strength (CS), modulus of rupture (MoR) and splitting-tensile strength (STS) were increased by 13%, 50% and 11% at 28 days compared to that of PC (Table 1). Song et al. studied the strength properties of nylon fiber reinforced concrete (NFRC) [29]. The mix design ratio for plain concrete was 1:2.83:3.5 with water-cement ratio of 0.65. The fiber content was 0.2% by cement mass, having a length of 19 mm. It was concluded that the compressive strength, splitting-tensile strength and modulus of rupture of the NFRC was increased by 12%, 17% and 6%, respectively, as compared to that of plain concrete (Table 1). Saxena and Saxena reported that the static and dynamic properties of matrix were improved using nylon fibers for prevention of crack propagation produced from internal flaws of matrix [30]. The compressive strength was investigated with different fiber content of nylon fibers (i.e. 0.2%, 0.25% and 0.3% of total volume of concrete). In plain concrete, cement was replaced with fly ash by 10%, 20% and 30%. It was concluded that 10% fly ash, 90% cement, and 0.2%, 0.25% and 0.3% nylon fibers gave improved compressive strength of concrete. The compressive, splitting-tensile and flexural strength of oil palm shell nylon fiber-reinforced concrete were enhanced as compared to that of plain concrete [31]. Nylon fiber reinforced concrete (NFRC) is tougher and ductile because the fibers have an important role in post cracking behavior [32]. As far as the global production of glass fiber is concerned, China is the largest manufacturer according to Transparency Market Research [33]. The global market for glass fiber includes Europe, Latin America, North America, Asia Pacific, Africa and Middle East. On the other hand, North America is the biggest manufacturer of nylon and Asia pacific is the biggest consumer [34].

To the best knowledge of authors, no study has been reported on application of GFRC and NFRC in bridge decks for enhancing durability. The durability of concrete bridge deck can be enhanced

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