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Flexural performance of a precast concrete slab with steel fiber concrete topping

Farnoud Rahimi Mansour, Suhaimi Abu Bakar *, Izni Syahrizal Ibrahim, Abdul Kadir Marsono, Bahram Marabi

Department of Structure and Materials, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM-Skudai, Johor, Malaysia

HIGHLIGHTS

- Increasing the flexural capacity of concrete slab by applying a steel fiber topping.
- Try to overcome certain problems by using steel fiber in concrete.
- The mechanism relies on a good bonding between the two layers.
- To provide a better results, roughness for interface has used.
- Flexural performance depends mainly on the type of roughness.

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ABSTRACT

The positive effects of various types of fibers on concrete ductility and other engineering properties, such as the tensile, flexural, fatigue, and load-bearing capacity after cracking and toughness, are well known. Steel fiber-reinforced concrete (SFRC) has been used increasingly in recent years and has been applied to various structural components. Considerable interest has been developed in using steel fibers in concrete to increase the load-carrying capacity of the structural members in service. It has been used recently to increase the flexural capacity of concrete slabs by applying a thin layer of SFRC onto an existing slab, a technique known as cement-base bonded overlay. The objective of this research is the investigation of the flexural behavior of a precast concrete slab with a steel fiber concrete topping. To reinforce the concrete overlay, hooked-end steel fibers with a length of 30 mm and a diameter of 0.75 mm were used. Because the performance of this composite slab depends on the bonding between the old and new concrete, different types of roughness at the interface has used to provide good bonding between the two layers. Based on experimental tests, the flexural performance was shown to depend not only on adding the steel fibers to the topping but also on the type of interface roughness. To examine the composite behavior of the specimens, the interface slip was also measured throughout the test. The results showed a good reliability of roughness in providing bonding strength at the interface. It was also found that roughness in the transverse direction provides the best bonding strength at the interface. Although the results showed interface slip at mid-span, slip was not detected at either end of the specimen.

1. Introduction

There are a number of situations where it may become necessary to increase the structural performance of concrete members. In recent years, the cement-base bonded overlay technique has been used to strengthen and enhance the structural performance of precast concrete slabs by adding a thin layer of cast in-situ reinforced concrete to the existing slab. The primary purpose is to improve the load-carrying capacity and stiffness of the slab by increasing its thickness. The efficiency of this strengthening technique strongly depends on the bonding between the added layers with the substrate. Debonding becomes possible because of cracking of the overlay and because of the tendency of the overlay not to follow the curvature of the substrate.

It is generally accepted that the main cause of overlay debonding is the cracking of the overlay due to one of the causes, or the superposition of the two causes, sketched in Fig. 1, designated as "mechanical origin" and "differential length change." Debonding of mechanical origin is shown in Fig. 1a. It is the consequence of

* Corresponding author. Tel.: +60 75531602.
E-mail address: suhaimibakar@utm.my (S. Abu Bakar).

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the flexural straining of the structure by the applied load. Debonding of differential length change is illustrated in Fig. 1b. It results from the effects of the different length changes of the overlay and base, especially because of shrinkage. In both cases, debonding results from a full depth separation of the overlay (e.g., a crack), preventing continuous stress transmission within the overlay. At the crack location, sharp built-in peak stresses develop at the interface, which subsequently cause debonding.

Reinforcement of the overlay enables force to be transmitted through the crack and decreases the intensity of the mechanical discontinuity at the crack location. Consequently, the built-in peak stresses at the interface decrease, delaying overlay debonding. Steel reinforcing in the form of tied bars and welded mats is normally used for overlay reinforcement. However, using steel bars or welded fabric behind thin covers lead to wide cracks and can only be used in relatively thick overlays [1]. Substitution of fibers in concrete is expected to overcome these problems and delay overlay debonding. Fibers are not affected by such constraints and, as a bonus, they present a reduced risk of corrosion [1]. Fibers also reduce the amount of steel bars required and accelerate the construction time because they are added directly to the concrete batch [2]. Although all types of reinforcement act in similar ways, the literature shows that fiber reinforcement has a higher effectiveness. The amount of fibers required to achieve the desired result will depend on the type of fiber and its bond characteristics.

It has been recognized that the behavior of concrete remarkably improves by reinforcing it with discontinuous fibers [3]. Studies have shown that fibers transfer loads to the uncracked parts of the concrete, prevent crack propagation, reduce brittleness and significantly improve the concrete's tensile strength, compressive strength, toughness, energy absorption capacity and durability [3,4]. Compressive tests showed that fibers in concrete had only a small effect on the compressive strength of concrete [5,6]. A main advantage of fiber reinforced concrete (FRC) is its high energy absorption capacity and high toughness due to its higher ductility [7]. According to a statement by Zollo, the fibers have more effect on the energy absorption capacity and crack control compared with the ultimate flexural strength [8]. This has also been confirmed by Khaloo and Afshari based on their investigation of the flexural strength, deflection and energy absorption of small concrete slabs [9].

Among other fibers, steel fibers (SF) have become popular in recent years because of their structural properties [3]. In 1963, Romualdi and Batson reported significant improvement in concrete properties through the use of a randomly distributed SF. Improved durability has been demonstrated by the previous research of cement-based bonded overlays with added SF. Today, hooked-end steel fiber (HSF) is mostly used due to its significantly improved reinforcement effects compared to straight SF [10]. A strong connection between the hydrated cement matrix and the HSF has been demonstrated based on experiments performed by Ackermann and the microscopy images of steel fiber reinforced concrete (SFRC) by Uygunoğlu [11].

The performance of the composite slab depends on the bonding behavior between the old and new concrete. The most reliable and economical solution to increase the bonding strength of the interface is the roughening the surface of the substrate. Although several studies have been carried out, there is still a lack of information on the effect of various types of roughness on the overall performance of the composite slab. The aim of this research is to evaluate the flexural capacity of precast slabs with a SF concrete topping related to different roughnesses of the substrate surface. To examine the composite behavior of the specimens, interface slip was also measured throughout the experiments.

2. Previous work

2.1. Mechanical properties of SFRC

The mechanical properties of SFRC mainly depend on the SF geometry, aspect ratio, volume fraction and concrete strength. It has been observed that concrete mixtures with waved SF exhibit higher compressive strengths than concrete mixtures with HSF [6]. Additionally, it has been shown that specimens with HSF exhibit higher toughness than specimens with waved SF [6]. Uygunoğlu showed that flexural strength is directly related to SF volume fraction, concrete age and aspect ratio, while crack development in bending is inversely related to these parameters [11]. A study by Khaloo and Afshari on small SF concrete slabs showed that the energy absorption increased as the SF volume, aspect ratio and concrete strength increased [9]. However, a reduction in the increasing rate of energy absorption was also shown when the content of SF was increased. The ductility of SFRC also improves with increasing SF content in volume; ductility was also shown to improve at the same SF content when the SF length was increased [5]. These phenomena are caused by the higher deformability and energy absorption of SFRC during the cracking phase and the fact that post-cracking behavior is affected by different SF lengths [5]. Although the higher SF aspect ratio may result in lower compressive strengths and elastic moduli, the toughness and peak strains of SFRC increase, which lead to more energy absorption and better crack control. A different study by Altun et al. on SFC with different

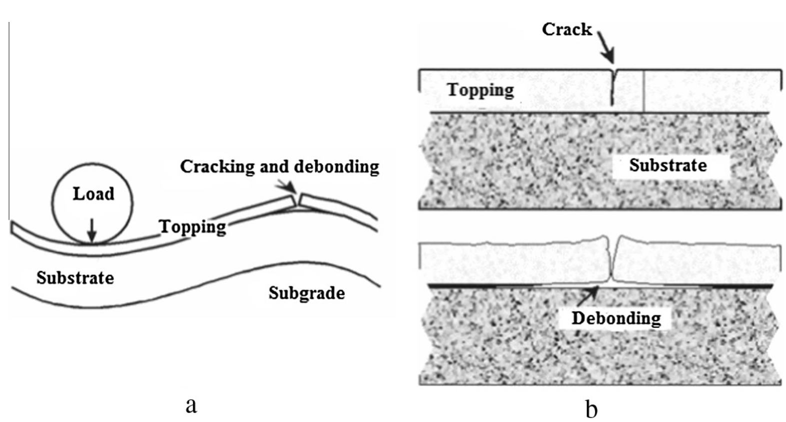

Fig. 1. (a) Debonding of mechanical origin and (b) debonding of differential length change [1].