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A feasibility of enhancing the impact strength of novel layered two stage fibrous concrete slabs

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ABSTRACT

This study pioneers the concept of a novel layered two stage fibrous concrete (LTSFC) subjected to falling weight collision. The LTSFC is a newly developed concrete, with unique combination of steel fibres and coarse aggregates that are premixed and preplaced in the formwork in three layers followed by a flowable grout injection in each layer to fill the voids. In this study, some LTSFC slabs were proposed to consider the combined effect of layered and two stage concrete containing different type and combinations of steel fibres. Nine slabs were proposed, casted and tested, for which firstly the LTSFC were prepared and reinforced in three layers of 4%, 2% and 4% with three different fibres viz., crimped fibre (CF), hooked end fibre (HF), combined CF and HF and combined long and short CF. Secondly, the slabs were reinforced with 3.3% of same type of steel fibres over the entire cross section. The average amount of fibre used in LTSFC specimen was 3.3% which is similar to the fibre dosage used in the second series, where the fibres are equally spread in entire cross section. The study parameters viz., number of repeated impacts that induce the first crack and failure, impact ductility ratio, crack resistance (service and ultimate) and impact crack resistance ratio were considered herein. The results indicated that LTSFC specimens exhibited significant increase in the number of repeated impacts for the initial crack and failure to occur, high crack resistance, enhanced ductility and impact crack resistance ratio when related with non-fibrous concrete. Hence, the most significant findings of this research should stimulate innovation and new technology to develop the novel LTSFC in future studies.

1. Introduction

In today's scenario, the increasing number of global terrorism activities and dynamic loading arising from earthquakes has made the high impact resistance capacity in civil and military infrastructures indispensable and this has enticed many researchers [1,2]. Additionally, impact scenarios include vehicle collisions on transportation structures, airport runway due to aircraft take-off and landing, wind gust and machine dynamics [3]. Nevertheless, as commonly known, concrete possess brittle nature with greater rigidity that usually exhibits sizeable damage like building collapse, causing losses of human life when exposed to impact loading [4]. Consequently, inventive building materials that can augment the ductility, high energy dissipation mechanism, damage tolerance, and restrain crack bridging, are much in demand. A possible scheme to attain an enhanced energy absorption capacity by using higher steel fibre dosage (5%) in two stage fibrous concrete (TSFC) [5].

The TSFC is a novel technique that differs from the conventional fibre reinforced concrete (FRC) in several aspects including its placement technique, implementation, fabrication methodology and high coarse aggregate and fibre content [6]. First, coarse aggregate and steel fibres are mixed together and preplaced into the mold, followed by grout injection (cement and fine aggregate grout mixtures) which is mixed separately [7]. Commonly, a gravity or pumping method of grouting process is adopted in TSFC [8]. In the gravity method, the cementitious grout is allowed to flow onto the mold through the preplaced packed aggregate and fibres that penetrates under its own weight to the bottom of the mold, subsequently, the flowing grout fills the voids between the aggregates. Nevertheless, this technique is practically appropriate to a maximum of 300 mm thickness of concreting [9]. In the pumping method, a network of injection pipes is placed at the bottom of the mold in which the grout is injected from beneath the preplaced aggregate and injection pipes are slowly moved up throughout the grout pumping process [10].

TSFC is a unique fabrication process and it has been successfully employed for various applications including underwater construction, massive concrete structures and nuclear power plant structures etc. [11]. TSFC has 60% of the total volume of coarse aggregate while the

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conventional concrete has 40% of the total volume of coarse aggregate, TSFC has up to 5% of fibre dosage while the conventional FRC has up to 2% of fibre dosage, which implies that TSFC has higher coarse aggregate content and fibre content [6,12]. The coarse aggregate properties, water binder and sand binder ratio mainly affecting the mechanical properties of TSFC have been well established and investigated by several researchers [6,7,13–15].

In the last decade, there is a great raising awareness about the development of fibrous concrete with superior impact resistance. In recent, the research emphasis has shifted towards the functionally graded reinforced cementitious composites (FGRCC) which is a newly developed composites with the unique combination of high impact strength and ductility [16]. Mastali et al., (2015) investigated the effects on functionally graded reinforced concrete slabs (5 layer) under drop weight and projectile impact. The first and fifth layer were reinforced with 2% steel fibre, second and fourth layers were reinforced with 1% steel fibre and third layer with 2% steel fibre. It was concluded that the functionally graded reinforced concrete possess enhanced impact resistance, reduction in penetration depth and showed high efficiency. Ghasemi Naghibdehi et al., (2014) on investigating the performance of slab by utilizing FGRCC, concluded that increasing fibre dosage or employment of reinforced concrete in top, bottom layers or over entire cross section, not all the times enhances its performance as it sometimes declines the performance of slab [17]. In this context, this paper examines the impact response of novel LTSFC under the falling weight collision on thin slabs and compared with two stage plain concrete slab. However, the effect of unique combination of layered and two stage fibrous concrete under impact load is still unexplored and need special focus.

2. Research significance

Despite the plenitude of open literature data on mechanical properties of two stage concrete and layered concrete however its combined performance especially under falling weight collision is still scarce and needs special emphasis. The impact strength performance of the conventional FRC is well documented; however, for LTSFC this has not been duly examined. Several guidelines have been suggested to assess the impact strength of FRC, in which ACI committee 544 [18] suggests the drop weight test and this has been used by several researchers [19–22]. So in the context of this background, for the first time, the authors have newly invented LTSFC slabs made with steel fibres that were premixed with aggregate and preplaced in three layers (top and bottom layer containing 4% fibre dosage and middle layer containing 2% fibre dosage) in the mold followed by grouting. Also, this research program aimed to examine the number of repeated impact that induce the first crack and failure, impact ductility index, crack resistance (service and ultimate) and impact crack resistance ratio of TSFC and LTSFC slabs.

3. Experimental work

3.1. Materials

Ordinary portland cement of grade 43 following to IS:8112-2013 [23] having a specific gravity value 3.14. Fine aggregates utilized were locally available natural river sand with a specific gravity of 2.56 which is confirming to IS:383-2016 [24]. Coarse aggregates made with crushed granite gravel of nominal size 12 mm and 18 mm with a specific gravity of 2.65 were utilized to prepare all mixtures. Fig. 1 shows the geometry of three type of fibres employed namely hooked end and crimped steel fibre with a length and diameter of 30 mm and 0.5 mm respectively and short crimped steel fibre with a length of 12 mm, a diameter of 0.4 mm. The yield strength of hooked end, crimped and short crimped steel fibres were 1100 MPa, 1100 MPa and 1050 MPa respectively.

3.2. Mix proportions

Totally, nine mixtures were prepared in this experimental program, for all nine mixtures, the water-to-binder and sand-to-binder ratio were kept as 0.45 and 1.0 respectively. It is worth to be stated that the fine sand is found more suitable for preplaced aggregate concrete to produce flowable grout in a coarse aggregate and fibres skeleton. To improve flowability of grout, a polycarboxylic ether based high-performance superplasticizer (master glenium SKY 8233) was used in all mixtures to guarantee the efflux time of 35–40 ± 2 s according to ACI 304.1 and ASTM C939/C939M – 16a [25,26]. Fig. 2(a) demonstrates the TSFC (M2 and M4) slabs that were reinforced with 3.3% of hooked end and long crimped steel fibres respectively. The M6 slab was reinforced with 3.3% from which 50% of hooked end fibres and remaining 50% of long crimped steel fibres. Likewise, the M8 slab was reinforced with 3.3% from which 50% of long crimped fibres and remaining 50% of short crimped fibres. All TSFC slabs were reinforced with 3.3% of different fibre type in entirely reinforced cross section. Fig. 2(b) demonstrates the LTSFC mixtures: M3, M5, M7 and M9 slabs that were reinforced in three layer with 4%, 2% and 4% fibre dosage at the top, middle and bottom respectively. A same fibre series were used for the LTSFC slabs as that of the fibre series used in case of TSFC slabs. The average amount of fibres utilized in LTSFC specimen was 3.3% which is similar to the fibre dosage utilized in entirely reinforced cross section. The quantity of ingredients and fibre layer details of all nine mixtures are listed in Table 1.

3.3. Specimen preparation

To evaluate the impact strength and compressive strength, a slab size of 600 mm × 600 mm × 60 mm and 150 mm cubic specimens were employed respectively. Firstly, the combination of steel fibres and coarse aggregates were preplaced in single layer (for TSFC) and three layers (for LTSFC) into the formwork as shown in Fig. 3(a). Subsequently the flowable grout (gravity method) was injected through the top layer of preplaced aggregate and steel fibres to fill the voids, thus eliminating the compaction process as shown in Fig. 3(b). The specimen after grouting and hardening is shown in Fig. 3(c) and (d). During casting specific care has to be taken that the grout should not be leaked out of the gaps since grout constitute the quality of the mixes. Each of the specimens were cured under standard curing (20 ± 2 °C) for 28 days prior to testing.

3.4. Test configuration and instrumentation

The compressive strength was determined on 150 mm cubic specimens in conformity with IS: 516-1959 [27]. The impact strength of proposed slabs were achieved in compliance with the guidelines conferring to ACI committee 544 [18]. According to ACI committee 544, all specimens were subjected to impact loading induced by steel ball mass of 4.45 kg frequently released from 457 mm height on the top surface of centre of the slab. The number of repeated impacts for the initial crack and failure to occur were observed as first crack strength (IC) and failure strength (FR) respectively. Fig. 4 illustrates the repeated falling weight collision test device.

The impact energy at initial crack and failure were calculated according to Eq. (1).

$$Impact\ Energy\ (U) = n \times m \times g \times h \tag{1}$$

where n = number of repeated impacts for the first initial crack and failure to occur; m = weight of steel ball with a mass of 4.45 kg; g = acceleration of gravity (9.81 m/s^2); and h = falling height of steel ball (457 mm).