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Characterisation of macro polyolefin fibre reinforcement in concrete through round determinate panel test

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HIGHLIGHTS

- Reinforcing effects of polyolefin fibres in concrete was studied through RDPT.
- Effects of fibre length, dosage and concrete strength on concrete toughness were studied.
- A new characterisation method using toughness index based on RDPT was presented.
- A combined synergetic effect of fibre length, dosage and concrete strength was found.
- Equivalent reinforcement was achieved by adjusting combinations of fibre dosage, length and concrete strength.

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ABSTRACT

Macro polyolefin fibres can effectively improve flexural toughness and post-cracking performance of concrete, they are hence becoming popular in various constructions. This research focused on quantifying reinforcing effects of macro polyolefin fibres in concrete using round determinate panel test. Effects of fibre length, fibre dosage and concrete strength on the toughness of fibre reinforced concrete were investigated. A new characterisation method using toughness index was preliminarily attempted to introduce. It reflects the degree to which the fibre changes the toughness of plain concrete. It also "normalises" the toughness into approximately the same magnitude with other flexural tests, making it possible to compare with different flexural tests.

1. Introduction

Concrete has been widely used in construction industry as all the raw materials required for producing concrete are of low cost and are widely available around the world. Concrete has very high compressive strength, but it is weak in tensile strength and toughness. In order to improve its tensile strength and toughness, steel reinforcement [1] and various fibres such as steel fibres [2], synthetic fibres [3], glass fibres [4] and natural fibres [5] are often used to reinforce concrete.

Steel fibre is one of the most popular reinforcing materials in concrete due to its exceptional mechanical performance. However, high dosage rate of steel fibre is hard to disperse evenly in concrete and requires changes in concrete mix. In the tunneling and underground constructions, steel fibre reinforced concrete requires significant maintenance due to corrosion of steel. Besides, steel fibre sometimes damages equipment, and causes rebound injury in the shotcrete. Therefore, macro polyolefin fibres have attracted widespread attention and have become popular for constructing concrete footpaths [6], bridge deck pavement [7], precast elements [8] and shotcrete mine tunnels [9].

Macro polyolefin fibre is made of either polypropylene or high-density polyethylene. It has a length of 30–60 mm and a cross section of 0.6–1.5 mm^2. It has a tensile strength of 300–600 MPa and a Young's modulus of 4–10 GPa depending upon the manufacturing techniques [3]. Two techniques have been widely adopted to produce macro polyolefin fibre. The first technique involves melt spinning polyolefin granules into filaments and then hot drawing the monofilaments into fibres [10]. Another processing technique is

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extruding polyolefin granules through a rectangular die to form film sheets (0.2–0.5 mm thick), before slitting the sheets longitudinally into equal width tapes (1.0–1.3 mm wide) by a slitting machine [11]. Density of macro polyolefin fibre is about 0.9 g/cm^3, which is much lower than steel fibre (7.8 g/cm^3). However, dosages of either steel fibre (20–60 kg per m^3 concrete [12]) or macro polyolefin fibre (4–8 kg per m^3 concrete [13]) have little influence in the whole weight of concrete (1.8–2.4 t/m^3).

Macro polyolefin fibre can convert the brittle plain concrete into a tough material with enhanced crack resistance and ductility [14]. The fibres in concrete can bridge concrete cracks, reducing stress intensity at crack tip and preventing propagation of the crack tip. In addition, the fibre bridging can decrease crack width, which prevents water and contaminants from entering the concrete matrix to corrode reinforcing steel and degrade concrete [15]. Although every individual fibre makes a small contribution, the overall effect of reinforcement is cumulative.

Among the various methods of characterising toughness of concrete, flexural tests are easy to conduct and can simulate most of engineering situation. Hence, the flexural tests have been widely adopted by the industry [15]. Most of the available European and American standards and guidelines recommend the use of unnotched beam specimens subjected to four-point loading, such as ACI Committee 544 [16], ASTM C1018 [17], ASTM C1399 [18], and ASTM C1609 [19]. A three-point bending test on a notched specimen, based on ASTM E1290 [20] and BS EN 14651 [21], is becoming increasingly popular to study the post-cracking behaviour of fibre reinforced concrete. Other standards, such as JSCE-G552 [22], JSCE-SF4 [23], and RILEM TC162-TDF [24] are also used to evaluate the toughness of fibre reinforced concrete.

Among these standards, round determinate panel test (RDPT), according to ASTM C1550 [25], is considered as one of the most reliable test methods of post-cracking performance assessment [26]. It involves a centre point loading of a large circular plate supported on three points. The specimen toughness is assessed in terms of the energy absorbed in loading the plate at some selected values of central deflection of the panel. Its panel-based performance assessment is desirable as panels fail through a combination of stress actions that reflect behaviour of concrete more closely than other mechanical tests in the laboratory [1]. Moreover, based on the standards of beam test, such as ASTM C1609 [19] and BS EN 14651 [21], the cross section of beam is 150 mm × 150 mm, which is too small to evenly disperse long fibres (such as 60 mm long fibres) in the mould. The fibres are easy to be oriented or affected by the walls of mould. Bernard [27] investigated possible correlations in behaviour between flexural beam and panel specimens to determine the most appropriate type of test for a given fibre reinforced shotcrete application. Based on 62 sets of specimens, representing more than 360 beams and 360 panels, Bernard [27] found that fibre reinforced shotcrete RDPT specimens display a markedly lower variation in post-cracking performance than beams. He concluded that the most reliable method of post-cracking performance assessment is by calculating energy absorption from the round determinate panel tests.

This research focuses on quantifying reinforcing effects of the macro polyolefin fibres in concrete using RDPT test. The effects of fibre length, fibre dosage and concrete matrix strength on the toughness of fibre reinforced concrete were investigated. A new characterisation method using toughness index was preliminarily introduced in order to reflect the degree to which the fibre changes the toughness of plain concrete. This "normalises" the toughness into approximately the same magnitude as other flexural tests, making it possible to compare with different flexural tests.

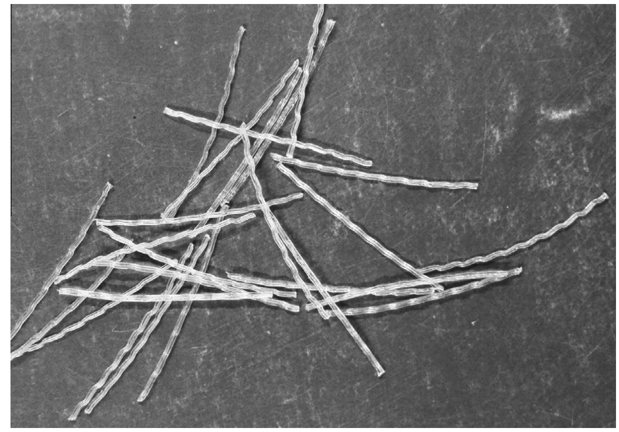

Fig. 1. Macro polyolefin fibre.

2. Material properties and experimental work

2.1. Macro polyolefin fibre and concrete mix design

The macro polyolefin fibres used in this research (Fig. 1) have diameter of 1.0 mm and lengths of 38, 48 and 60 mm. Tensile strength, Young's modulus and elongation at break of the fibre is 550 MPa, 10 GPa and 8%, respectively. The fibre dosages of 3, 6 and 9 kg/m^3 were used in this study. Two types of concrete mix design with target compressive strength of 30 and 40 MPa used in the study are shown in Table 1. The average slump of control mix (plain concrete) was 60 mm, while the average slumps of fibre reinforced concretes ranges from 50 mm to 30 mm, with the decrease in the slump observed with the increase in fibre dosage and fibre length. Specimen names are listed in Table 2, where the numbers after FC are concrete strength grade, fibre length and fibre dosage, respectively. Based on the ASTM C1550 [25], round panels of 800 mm in diameter and 75 mm in thickness were casted. The panels were allowed to stand for 24 h in laboratory before demoulding. The specimens were then cured in water at 23 ± 2 °C for 28 days.

2.2. Round determinate panel test

Round determinate panel specimens were tested in flexure based on ASTM C1550 [25]. As shown in Fig. 2, a central point load was applied on the round panel supported on three symmetrically arranged hinged supports. The three pivoted supports ensured that load distribution was always determinate in the round panel specimens. A hydraulic universal testing machine with a capacity of 250 kN was used for applying the load. As specified in the standard, the load piston advanced at a constant rate of 4.0 ± 1.0 mm/min up to a central displacement of 45.0 mm. The deflection was recorded by a Linear Variable Deflection Transducer (LVDT) placed under the centre of specimen. Average values for three samples of each type of fibre reinforced concrete and plain concrete tested were obtained.

3. Characterisation of toughness index

Based on the ASTM C1550 [25], the toughness of fibre reinforced concrete is considered as its ability to absorb energy, which is characterised by the areas under the load-deflection curves obtained experimentally through the centrally loaded round determinate panel test (RDPT). Although this characterisation effectively measures the post-cracking behaviour of fibre reinforced concrete,