Composite Structures 152 (2016) 20–33

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Bond-flexural behaviour of structural nano-synthetic fibre-reinforced cementitious composites

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ARTICLE INFO

Article history:
Received 4 April 2016
Accepted 10 May 2016
Available online 11 May 2016

Keywords:
Bond
Cementitious
Interfacial
Nano-clay
Pull-out
Structural synthetic fibre

ABSTRACT

Prior studies have shown that the bond properties of structural nano-synthetic fibre in a cement matrix improved as the shape of the fibres became more three-dimensional. The maximum pull-out resistance strength increased but improvement of interfacial toughness did not follow due to fibre fracture. In this study, cementitious composites containing structural nano-synthetic fibres that improved the bond properties were examined for their flexural properties. The relationship between the bond and flexural properties were studied as a function of fibre volume fraction and shape; the straight type of fibre was also examined as a control. It was found that the flexural toughness increased with increasing fibre volume fraction. For the twisted type of fibre, the maximum residual flexural strength decreased with increasing crack mouth opening. However, the twisted + crimped type of fibre displayed stable post-peak behaviour with continuously increasing residual strength.

1. Introduction

The ductility of a fibre-reinforced cementitious composite is characterised by an energy-dissipation mechanism that depends on the bond characteristics between the fibre and the cement matrix and the pull-out characteristics of the fibre [1–5]. If cracking occurs, the cement matrix cannot resist further against the applied tensile stress and the entire load is carried over to the fibre. With increasing applied load, the fibre transfers additional stress to the cement matrix via the bond stress [6]. During this process, multiple cracks appear until fibre fracture occurs, or local debonding by the cumulative load leads to fibre pull-out. Through this process, the strain of a fibre-reinforced cementitious composite increases to the maximum load, and its ductility provides a high toughness beyond the ultimate load. The degree of toughness enhancement is greatly affected by the volume fraction and pull-out resistance of the fibre [6–9]. Therefore, for a ductile fibre-reinforced cementitious composite, the fibre should not readily fracture and should have a suitable pull-out behaviour from the cementitious composite.

The fibre pull-out behaviour is defined by the bond characteristics between the fibre and the cement matrix. A typical way to improve the bond characteristics is to increase the specific surface area in contact with the cement matrix by changing the shape of the fibre [9,10]. A fibre-reinforced polymer whose hydrophobicity was improved by incorporating a nanoclay also showed enhanced bond properties when the shape of the fibre reinforcement was changed [11]. A preliminary study analysed the relationship between the properties of a structural nano-synthetic fibre and its bond and flexural properties when used as reinforcement in a cementitious composite.

2. Materials and mix proportions

2.1. Structural polymeric nanoclay synthetic fibre

Herein, the flexural behaviour was evaluated as a function of the shape and volume fraction of the structural nano-synthetic fibre. The structural nano-synthetic fibre used as the control was of the straight type with a diameter of 0.60 mm and a length of 50 mm. Three other shapes were studied: crimped, twisted, and twisted + crimped (Fig. 1).

The structural nano-synthetic fibre was manufactured by melt spinning of a master batch using a single-screw type of equipment. Master batch refers to the preparation of chips of polymer powder containing an organic nanoclay (Cloisite 20A, Southern Clay Products, USA) having an inter-layer distance of 20 Å. The master batch was made with 25 wt% of nanoclay by first compounding with a 2:3 w/w ratio of nanoclay and a compatibiliser (maleic anhydride-g-polypropylene) and then with a 1:3 w/w mixture of virgin polypropylene and nanoclay. The final master batch containing

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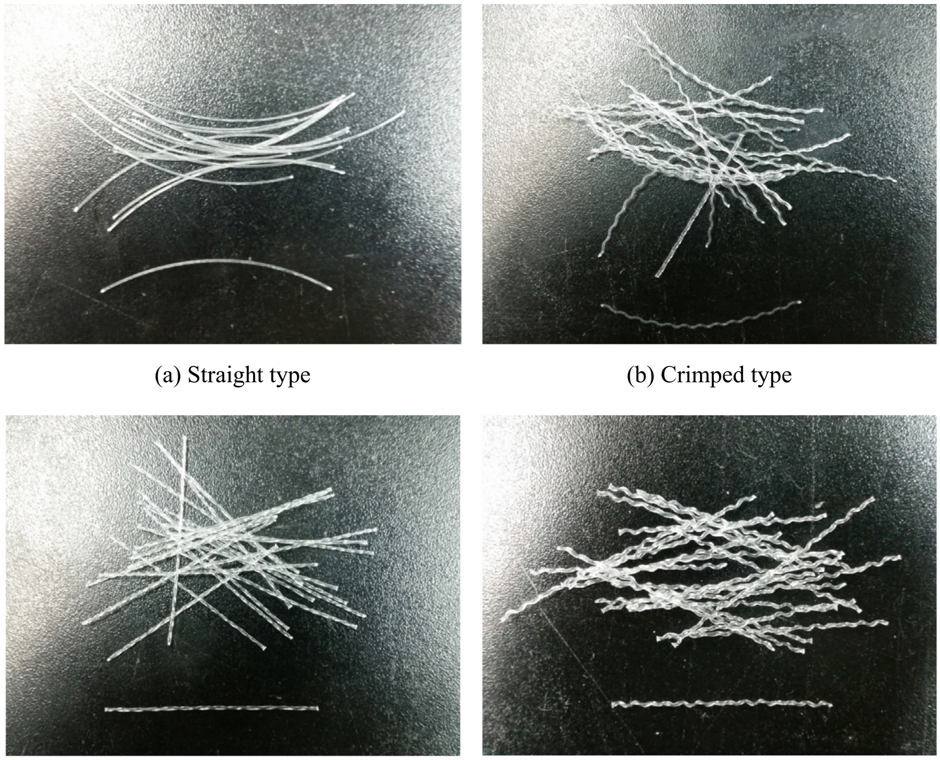
http://dx.doi.org/10.1016/j.compstruct.2016.05.041
0263-8223/



(a) Straight type (b) Crimped type

(c) Twisted type (d) Twisted+crimped type

Fig. 1. Shapes of the structural nano-synthetic fibres [11].

Table 1
Properties of the structural nano-synthetic fibre [11].

Type	Aspect ratio	Specific gravity	Tensile strength (MPa)	Ultimate elongation (%)	Acid/alkali resistance	Electrical conductivity
Structural nano-synthetic fibre	83	0.91	578.7	19.1	High	Low

the structural nano-synthetic fibre at nanoclay concentration of 0.15% was made by compounding with pure polypropylene at a 1:20 w/w ratio. The properties of the master batch are listed in Table 1. The properties of mixtures of the master batch with pure polypropylene depended on the mixing ratio. In this study, we used an elevated polypropylene ratio and a high drawing ratio to obtain a structural nano-synthetic fibre-reinforced polymer with a higher tensile strength than found for conventional structural synthetic fibres.

2.2. Cement and aggregates

Type I cement with a specific gravity of 3.15 was used. Crushed sand with a specific gravity of 2.62 and a fineness modulus of 3.07 was used as the fine aggregate. Crushed stone with a specific gravity of 2.64 was used as the coarse aggregate.

2.3. Mix proportions

A preliminary study found that incorporation of a nanomaterial and a three-dimensional structural nano-synthetic fibre improved the interfacial toughness bond property by 15–106% [11]. A mix having a design compressive strength of 40 MPa was prepared and characterised by measuring its flexural properties as functions of the shape and volume fraction of the structural nano-synthetic fibre. The volume fraction of the structural nano-synthetic fibre was 0.2–0.5 vol%. Table 2 lists the experimental variables and the mix proportions. The mixtures are identified as follows: the prefix designates the fibre type (Tw for twisted, Cr for crimped, TC for twisted + crimped and St for straight) and the

Table 2
Mix proportions.

Type of mixture	W/B (%)	S/a (%)	Unit weight (kg/m^3)				Fibre dosage (vol%)
			W	C	S	G	
Plain	47.1	47.8	172.9	367	868.2	948	–
NSt02							0.2
NSt03							0.3
NSt04							0.4
NSt05							0.5
NCr02							0.2
NCr03							0.3
NCr04							0.4
NCr05							0.5
NTw02							0.2
NTw03							0.3
NTw04							0.4
NTw05							0.5
NTC02							0.2
NTC03							0.3
NTC04							0.4
NTC05							0.5

St: straight type.
Cr: crimped type.
Tw: twisted type.
TC: twisted + crimped type.