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Combined effects of water film thickness and polypropylene fibre length on fresh properties of mortar

L.G. Li [a], Z.W. Zhao [b], J. Zhu [a,*], A.K.H. Kwan [c], K.L. Zeng [a]

[a] School of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, China
[b] Architectural Design and Research Institute of Guangdong Province, Guangzhou, China
[c] Department of Civil Engineering, The University of Hong Kong, Hong Kong, China

HIGHLIGHTS

- Water film thickness (WFT) governs the fresh properties of fibre mortar.
- In polypropylene fibre mortar, fibre length has some effects on the WFT.
- The WFT and fibre length have combined effects on the fresh properties.
- Best-fit curves for estimating the fresh properties derived as design aids.

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ABSTRACT

Among the various characteristics of fibre, the fibre length is no doubt a major factor affecting the fresh properties of fibre-reinforced cement-based material. In previous studies, it has been revealed that the water film thickness (WFT) is the most important factor governing the fresh properties of plain cement-based material containing no fibres. However, there has been little research on whether the concept of WFT can be applied when fibres are added and thus the combined effects of WFT and fibre length are still not known. In this study, a number of fibre-reinforced mortar samples containing polypropylene (PP) fibres of different lengths were produced for packing density, flowability, cohesiveness and adhesiveness measurement. It was found that the fibre length has significant effects on the packing density and WFT, and substantial effects on the flowability, cohesiveness and adhesiveness. Good correlations of these fresh properties to the WFT and fibre length have been obtained, indicating that the WFT and fibre length are together the governing factors.

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1. Introduction

Incorporation of various kinds of fibres in cement-based materials has become a common technique to improve performance in modern concrete technology. For instance, steel fibres with or without hooks are added to increase tensile strength, ductility and crack resistance [1–3]. Polypropylene (PP) fibres are used to control plastic cracks and improve fire resistance [4–7]. Polyethylene (PE) or polyvinyl alcohol (PVA) fibres are essential ingredients of engineered cementitious composites (ECC) [8–10]. Carbon fibres are particularly effective in increasing strength, and furthermore also play an important role in imparting electrical conductivity to the mortar or concrete produced [11–13]. Recently, with the advent of nano technology, carbon nanofibres and carbon nanotubes have emerged as top of the range fibres for further advancement of fibre-reinforced cement-based materials [14–16].

Among the various characteristics of fibre, the fibre length is no doubt a major factor affecting the performance of fibre-reinforced cement-based materials. In this regard, Ahmed and Mihashi [17] investigated the strain hardening of lightweight ECC made of hybrid PVA fibres and revealed that there are optimum combinations for best performance. Branston et al. [18] found that the improvement in concrete strength was better when longer basalt fibres were used. Mastali et al. [19] showed that as the length of carbon fibres increased, the impact resistance and some other mechanical properties were also increased. Maluk et al. [20] demonstrated that concrete with longer PP fibre added was better in terms of spalling resistance during fire.

* Corresponding author.
E-mail addresses: ligu@gdut.edu.cn (L.G. Li), 15920126593@163.com (Z.W. Zhao), jzhu@gdut.edu.cn (J. Zhu), khkwan@hku.hk (A.K.H. Kwan), zengkailong0914@qq.com (K.L. Zeng).

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Apart from the effects on the hardened properties, the fibre length also has important effects on the fresh properties of cement-based materials. In 2006, Banfill et al. [21] studied the rheology of carbon fibre-reinforced cement mortar and found that increasing the fibre length would increase both the yield stress and plastic viscosity. In 2012, El-Dieb and Taha [22] added steel fibres with different lengths to self-compacting concrete (SCC) to investigate their effects on the flow characteristics of SCC and proposed acceptance criteria for fibre-reinforced SCC. In 2015, Ghernouti et al. [23] employed plastic bag waste fibres with varying lengths of 2, 4 and 6 cm to produce fibre-reinforced SCC, and found that as the fibre length increased, the passing ability markedly decreased, indicating that the fibre length is an important parameter to be considered in the design of fibre-reinforced SCC.

Since when fresh, a cement-based material is a water–solid mixture, the water content has substantial effects on the fresh properties. However, it is actually the excess water, i.e. the water in excess of that needed to fill the voids between the solid materials, that forms water films coating the solid materials to provide lubrication and impart flowability to the water-solid mixture [24,25]. Recently, it has been proved that the water film thickness (WFT), which may be determined as the excess water volume to solid surface area ratio and has the physical meaning of being the average thickness of water films coating the solid materials, is the most important factor governing the fresh properties of plain cement-based material containing no fibres [26–32]. However, up to now, there has been little research on whether the concept of WFT may also be applied to fibre-reinforced cement-based material.

In this study, the concept of WFT was extended to PP fibre-reinforced mortar and the combined effects of WFT and fibre length on the fresh properties were investigated. PP fibres were selected for investigation first because they are relatively inexpensive and quite commonly used. An experimental program was launched, wherein mortar mixes with varying combinations of water/cement ratios and fibre lengths were made for testing. From the packing density results, the WFT of every mortar mix was evaluated and then the fresh properties of the mortar mixes were correlated to the WFT and fibre length by regression analysis. Although only PP fibres were used in this study, the research findings may also be applicable to other types of fibres or at least could be used as useful reference for the future development of a rheological model for fibre-reinforced cement-based materials.

2. Experimental program

2.1. Raw materials

The cement used was an ordinary Portland cement (OPC) of strength class 42.5 N supplied by local market. The fine aggregate employed was standard sand normally used for cement strength tests [33] with the particles >1.18 mm removed by mechanical sieving and has been tested to have a fineness modulus of 2.04. The specific gravities of the cement and fine aggregate have been measured as 3.11 and 2.66, respectively. A laser diffraction particle size analyzer was used to measure the particle size distribution of the OPC, whereas a mechanical sieving method was used to measure the particle size distribution for the fine aggregate, both of which are plotted in Fig. 1. From the particle size distributions of the OPC and fine aggregate, the specific surface areas of the OPC and fine aggregate were calculated as 1.55×10^6 and 2.16×10^4 m^2/m^3, respectively.

Polypropylene (PP) fibres with a diameter of 30.5 μm, a specific gravity of 0.91 but different lengths of 3, 6, 9, 15 and 19 mm (as shown in Fig. 2) were used. More details of the PP fibres are listed in Table 1. From the diameter, the specific surface area of the PP fibres was calculated as 1.31×10^5 m^2/m^3.

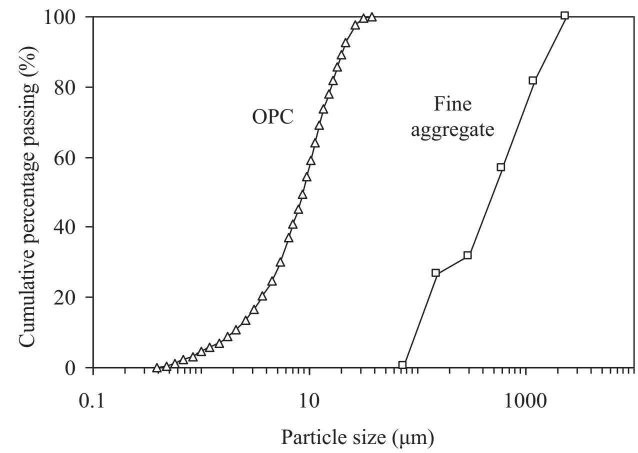

Fig. 1. Particle size distributions of OPC and fine aggregate.

Lastly, the superplasticizer (SP) added to each mortar mix was a commonly used admixture of the polycarboxylate-based type. It has a solid mass content of 20% and a specific gravity of 1.03.

2.2. Mix proportion

To investigate the combined effects of WFT and fibre length on the fresh properties of mortar, an experimental program was launched, in which the PP fibre content by mass of cement was fixed at 0.20%, the aggregate to cement (A/C) ratio by mass was fixed at 1.0, but the water to cement (W/C) ratio by mass was varied among 0.25, 0.30, 0.35 and 0.40, and the fibre length was varied among 3 mm, 6 mm, 9 mm, 15 mm and 19 mm. The SP added to each mortar mix was at a constant dosage of 0.5% measured in terms of liquid mass of SP by mass of cement.

For easy identification, each mortar sample was assigned a sample number in the form of X-Y, where X denotes the fibre length and Y denotes the W/C ratio by mass, as listed in the first columns of Tables 2 and 3. A total of 20 mortar samples were produced for testing.

2.3. Static and dynamic flowability measurement

A mini slump cone test [27] was used to measure the slump and flow spread of the mortar samples. The mini slump cone has a base diameter of 100 mm, a top diameter of 70 mm and a height of 60 mm. After the test, the slump was measured as the drop in height of the mortar, whereas the flow spread was measured as the average diameter of the patty formed minus the base diameter of the slump cone, both of which were taken as measures of the static flowability of the mortar. Likewise, a mini V-funnel test [27] was applied to measure the flow rate of the mortar samples. The mini V-funnel has a base opening of 30 mm × 30 mm, a top opening of 30 mm × 270 mm and an overall height of 300 mm. After the test, the flow rate was calculated as the volume of the mortar sample in the V-funnel divided by the flow time (the time from the start of the flow to the first sight of light through the opening). The flow rate so obtained was taken as a measure of the dynamic flowability of the mortar.

2.4. Cohesiveness and adhesiveness measurement

A modified version of the sieve segregation test [27] was used to measure the cohesiveness (the ability of staying together or

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