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Roles of water film thickness and fibre factor in workability of polypropylene fibre reinforced mortar

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ABSTRACT

For plain mortar without fibres, it has been found that its fresh properties are governed mainly by the water film thickness (WFT). For fibre reinforced mortar with fibres added, it has been suggested that the effects of the fibres may be evaluated in terms of a fibre factor (FF) combining the fibre volume and aspect ratio together. In two previous studies on the workability of polypropylene (PP) fibre reinforced mortar, the combined effects of WFT and fibre volume and the combined effects of WFT and fibre length have been separately studied. Herein, additional tests with both the fibre volume and fibre length varying simultaneously have been carried out to generate more data for evaluating the combined effects of WFT, fibre volume and fibre length. Based on the test results, a new model is developed whereby the workability attributes are each expressed as a single-variable function of the product of a linear function of WFT and an exponential function of FF. By this model, the roles of WFT and FF are revealed and the workability may be estimated for preliminary design of PP fibre reinforced mortar.

1. Introduction

Concrete and mortar, or generally cement-based materials, inherently have low tensile strength and tend to crack, causing serviceability and durability problems [1–3]. One good way of controlling cracking is to provide fibre reinforcement in the concrete and mortar. Various types of fibres, such as steel fibres, glass fibres, basalt fibres, polymer fibres, carbon fibres and even carbon nanotubes, have been added into the cementitious materials matrix to form fibre-reinforced cement-based materials (FRCM) [4–12]. Generally, FRCM with fibres added to control cracking have much higher tensile strength, abrasive resistance, impact resistance, ductility, toughness and fire resistance [13–18]. Among these fibres, polypropylene (PP) fibre is quite widely used due to its relatively low cost, good corrosion resistance, high effectiveness in crack control and high fire resistance [19–22].

Extensive studies on the effects of the fibre type, fibre content, fibre length, and fibre orientation on the various hardened properties of FRCM have been carried out [23–26]. Basically, the fibres are more effective in improving the hardened properties when the fibres are long and thin, and the fibre orientation aligns with the principle tensile stress. However, whilst the addition of fibres would significantly improve the hardened properties, it would also have certain adverse effects on the fresh properties, thus rendering the FRCM produced more difficult to place and compact than with no fibres added. Unfortunately, the effects of the various fibre parameters on the fresh properties are fairly complicated and up to now not fully understood, despite many years of research, as cited below.

In general, due to their hindrance to the deformation and movement of the matrix, the fibres added would decrease the workability of the concrete or mortar produced and thus increase the water demand and paste demand [26–29]. Hence, it is particularly difficult to produce a self-consolidating FRCM, which is required to have high flowability, cohesiveness and passing ability. For this reason, Ponikiewski and Katzer [30] suggested that for a self-consolidating FRCM, polymer

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fibres with 19 mm length may be added up to a volume fraction of 0.6% only and polymer fibres with 38 mm length are not suitable at all. Nevertheless, Kamal et al. [31] demonstrated that the addition of a suitable amount of fibres to a concrete mix could reduce bleeding and improve cohesiveness.

Although it is not easy to predict the effects of fibres on the workability of FRCM, some sound explorations have been carried out. Hannant [32] revealed that the fibre volume and aspect ratio (length/diameter ratio) are two main factors affecting the workability of FRCM. Hughes and Fattuhi [33] integrated the fibre volume (V_f) and aspect ratio (L/D) to form the fibre factor $V_f^{1/2}$ (L/D) and found that there is good correlation between the workability of steel FRCM and this fibre factor. Ferrara et al. [34] included fibers into the particle size distribution of the solid skeleton through the concept of "equivalent specific surface diameter" and thus established a model for the mix design of self-consolidating FRCM.

In fact, even the prediction of the workability of plain concrete/mortar without fibres is not an easy task. Nevertheless, numerous studies have been conducted and it was generally found that the major factors affecting the fresh properties of mortar are the water content, packing density and solid surface area of the water-solid mixture [35–38]. Particularly, the authors' research group had found that the combined effects of these three factors may be evaluated in terms of the water film thickness (WFT) and that the WFT is the single most important factor governing the fresh properties of mortar [39–41]. This concept of WFT has also been employed by others to study the rheology of paste/mortar/concrete [42–45].

In two previous studies, the authors' research group had extended the concept of WFT to FRCM and investigated the combined effects of WFT and fibre volume [46] and the combined effects of WFT and fibre length [47] on the fresh properties of PP fibre reinforced mortar. The test results showed good correlations of the various workability attributes to both the WFT and fibre volume at a fixed fibre length and to both the WFT and fibre length at a fixed fibre volume. Hence, it is evident that the WFT plays an important role in the fresh properties of FRCM. However, due to limited scopes of these studies, the combined effects of WFT, fibre volume and fibre length have not been studied and no theoretical model for considering all these three factors integrally has ever been developed.

Herein, in order to study the combined effects of WFT, fibre volume and fibre length on the various workability attributes of PP fibre reinforced mortar, additional tests with both the fibre volume and fibre length varying at the same time were carried out. Furthermore, to determine the WFT in each mortar mix, the packing density of the blended solid particles plus PP fibres was measured by the wet packing method. Lastly, correlation of each workability attribute to the WFT and fibre factor (FF) by regression analysis revealed the roles of WFT and FF in the workability of PP fibre reinforced mortar.

2. Experimental details

2.1. Materials

The cement used was an ordinary Portland cement (OPC) of strength class 42.5 N complying with Chinese Standard GB 175-2007 [48]. The fine aggregate used was the standard sand normally used for cement strength test [49] with the particles larger than 1.18 mm removed by mechanical sieving. The specific gravities of the OPC and fine aggregate have been measured as 3.11 and 2.66, respectively. The particle size distributions of the OPC and fine aggregate were measured by a laser diffraction particle size analyzer and by mechanical sieving, respectively, as plotted in Fig. 1. From the particle size distributions, the specific surface areas of the OPC and fine aggregate were calculated as 1.55×10^6 and 2.16×10^4 $m^{2/m3}$, respectively. Moreover, the median size [50] and fineness modulus of the fine aggregate were calculated as 0.26 mm 2.04, respectively.

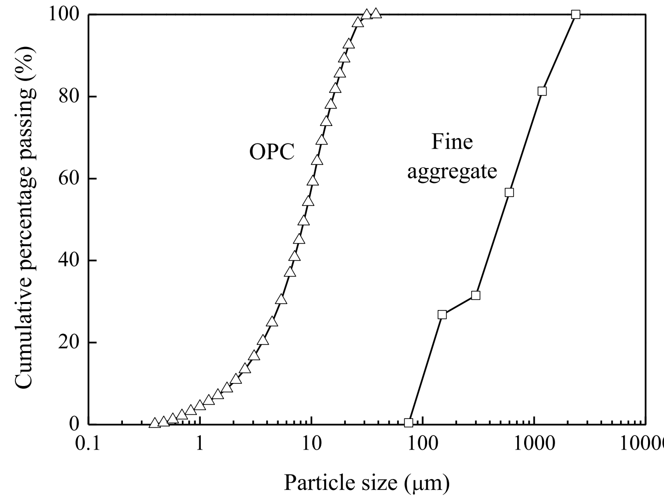

Fig. 1. Particle size distributions of OPC and fine aggregate.

On the other hand, the polypropylene (PP) fibres used have the same diameter (denoted by D) of 30.5 μm, but different lengths (denoted by L) of 3, 6, 9, 15 and 19 mm, as shown in Fig. 2. More details of this PP fibre are given in Table 1. From the diameter, the specific surface area of this PP fibre was calculated as 1.31×10^5 $m^{2/m3}$. 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. Experimental program

In the previous study, whereby the combined effects of WFT and PP fibre content were investigated [46], the PP fibre content by mass of cement was varied among 0.00%, 0.05%, 0.10%, 0.20%, 0.30% and 0.40%, while the fibre length was fixed at 6 mm, as depicted in Table 2. In the previous study, whereby the combined effects of WFT and PP fibre length were investigated [47], the PP fibre content by mass of cement was fixed at 0.20%, while the fibre length was varied among 3, 6, 9, 15 and 19 mm, as depicted in Table 3. In both studies, the water to cement (W/C) ratio by mass was varied from 0.25 to 0.40 in steps of 0.05, the aggregate to cement (A/C) ratio by mass was fixed at 1.0 and the SP dosage was set at 0.5% measured in terms of liquid mass of SP by mass of cement.

In this study, in order to provide additional data for investigating the combined effects of WFT, fibre content and fibre length, a third experimental program was launched in which the PP fibre content by mass of cement was varied among 0.30% and 0.40%, the fibre length was varied among 3, 9 and 19 mm, and the W/C ratio by mass was varied from 0.25 to 0.40 in steps of 0.05, as depicted in Table 4. As in the previous studies, the A/C ratio by mass was fixed at 1.0 and the SP dosage was set at 0.5% measured in terms of liquid mass of SP by mass of cement.

Each mortar mix was given a mix number in the form of X-Y-Z, where X denotes the PP fibre content (as a percentage by mass of OPC), Y denotes the fibre length (measured in mm) and Z denotes the W/C ratio by mass, as listed in Tables 2–4 In this study, 24 mortar mixes were produced for testing. Combined with the mortar mixes tested previously, the test results of a total of 68 mortar mixes were used to study the roles of WFT and FF in the workability of PP fibre reinforced mortar. The mix proportions of the control mortar with no fibres added are presented in Table 5.

2.3. Measuring workability

A mini slump flow test [40] was used to measure the slump and flow