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Fracture of High Content Polypropylene Fibre Reinforced Cement Mortar under Direct Tensile Loading

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Abstract

In this study, the tensile behaviour of high content polypropylene fibre reinforced cement mortar (PFRC) was investigated. A commercial type crimped shape polypropylene fibre was used at 5 different volume fraction: 1%, 2%, 3%, 4% and 5%. It was found that PFRC behaved differently depending on the fibre content (volume fraction). At 1%, the behaviour of PFRC was similar to that of plain cement mortar; there was a small sign of post-peak response. At higher content (2% to 4%), the responses of PFRC were essentially a double peak response. The load increased up to the point where cement mortar began to crack, follow by a quick drop of loading then the load recovery which resulted as the second peak at the larger deformation. At 5%, the PFRC exhibited a very ductile response, the larger numbers of fibres allowed the load to carry on without a drop even after the first crack. Evidently, the first peak strength of all PFRC specimens were quite similar as it was to cement mortar first crack strength.

1. Introduction

The use of fibres to reinforced brittle materials goes back at least to Egyptian times. The fibres used then were natural fibres, such as horsehair, straw, etc. In the early 1900s, the first commercialized asbestos fibres were introduced. Now, there are numerous fibre types available for commercial use, the basic types being steel, glass, synthetic materials (polypropylene, carbon, nylon, etc.) and some natural fibres.

The typical fibres volume fraction of FRC is in the range of 0.5% to 2.0%. The use of fibres may reduce the slump by about 25 to 100 mm depending on the type, volume fraction, and shape of the fibre [1-2]. Therefore, some adjustments to the fresh mix are required in order to obtain adequate workability with minimal segregation and bleeding, and to provide a uniform distribution of fibres. With higher fibre content (over 2.0%), special techniques for mixing and placing such as Slurry Infiltrating is required. In this technique, fibres are placed within a form or mold then infiltrating them with a fine-grained cement or mortar slurry.

Even though it is possible to mix such a high content FRC in the lab, it is still yet practical in the actual production because of its difficulty in mixing and placing. As a result of this, our understanding on the properties of high content FRC is still very much far from completed. Therefore, in this study, we are trying to take one more step to complete the big picture by carried out the test on PFRC at the fibre content up to about 5%. It is expected that with high fibre content, tensile behaviour of cement mortar would be quite different from those with lower fibre content.

2. Experimental Program

2.1 Cement Mortar Mix Proportion

The specimens were cast using the following materials:

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Cement : Type 1 Ordinary Portland Cement
Fine agg : Clean river sand with a fineness modulus of about 2.7

Table 1 Geometry of Fibres

Shape	Length (mm)	Section	Dia. (mm)
Crimped	58	Rectangle	1.0 x 0.5

Table 2 Cement Mortar Mix Proportion

Cement (kg)	Water (kg)	Fine Agg. (kg)	Superplasticizer[♣] (ml/kg of cement)
1	0.5	3	12-15

Table 3 Casting Schedule

Cement Mortar Type	% Vol. Fraction					Total
	1	2	3	4	5	
Plain Cement Mortar						3
Poly FRC	3	3	3	3	3	15

Fibres : Commercial type polypropylene fibre was used (Table 1) at five different volume fractions, 1%, 2%, 3%, 4% and 5%

The mix proportions shown in Table 2 were used throughout the tests, providing an average compressive strength of 35 MPa at 28 days based on ACI standard.

2.2 Specimen Preparation

The bone-shaped specimens were cast in the molds as shown in Figure 1. The molds were made of steel with an opening at both ends. Prior to the casting, the molds were lubricated with oil in order to ease the removing process.

Polypropylene fibres were mixed at 5 different volume fractions: 1%, 2%, 3%, 4% and 5%. Details casting schedule is given in Table 3. After removing from the molds, the specimens were then placed in water for 28 days for curing before subjected to test.

All tests were carried out at the Department of Civil Engineering, KMITNB using a 1500 kN universal testing machine[Ψ]. Specimens were held vertically at

Figure 1 Test Specimens.

Figure 2 Test Setup.

[♣] Naphthalene Based Commercial Type Superplasticizer "Daracem 19"

[Ψ] Instron 'Fast - Track 8800'

both ends of the machine by two slot grippers and the force was then applied directly at the rate of 0.05 in/min (Figure 2). The data were collected by a PC-based data acquisition system.

3. Experimental Results

3.1 Failure Patterns

Typical failure patterns of the specimens were given in Figure 3. As expected, the PFRC failed in more ductile manner with fibres partly pulled-out and partly fractured. There were signs of specimens being tortured during the fibres pulled-out process as seen by the occurrence of micro-cracks and uneven fractured surface. With fibres bridging across the cracks, more forces needed to be applied in order to overcome the fibre bond strength, and pull-out or fracture the fibres. After failure, the pieces of cement mortar were still held together by the fibres.

On the other hand, plain cement mortar specimens were found fail in a brittle manner. The fractured surface was flat and smooths with much less or no tortured sign because there was no fibre to prevent crack from propagating. Once the applied load and energy was large enough to cause the cracks to self propagate, failure took place catastrophically.

(a) (b)

Figure 3 Failure Patterns of (a) Plain Cement Mortar, and (b) Polypropylene FRC.

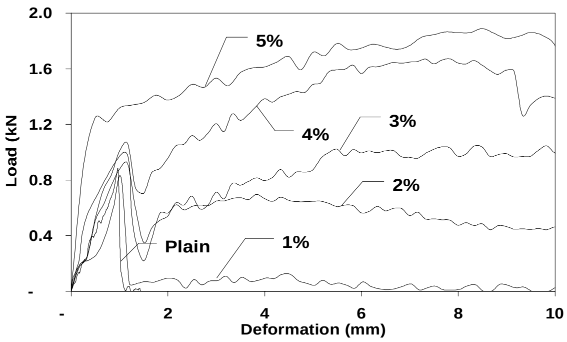

Figure 4 Load-Deformation Responses of Plain and Polypropylene Fibre Reinforced Cement Mortar Specimen Subjected to Direct Tension.

3.2 Load-Deformation Responses

Typical load-deflection response of the PFRC and plain cement mortar is as shown in Figure 4. PFRC specimens seemed to behave differently depending on the fibre content. At the lowest content using in this study (1%), the response of PFRC was essentially a single peak response with load increased up to the peak followed by a fast drop in load carrying capacity. There was a sign of load recovering, though very small and can simply be ignored. With the increasing fibre content (2% to 4%), the behaviour of PFRC changed to a double peak response with the recovery response became more obvious. After a fast drop of load after the first cement mortar crack, the load started to pick up slowly and recovery back to create another peak. In some cases (3% and 4%), the recovery was so significant that the second peak was even larger than the first peak. The recovery was solely due to the properties of the polypropylene fibre which will be discussed later.

In the case of the first peak load, it was found to be unchanged (or increase slightly) with the increasing fibre. This was because of the low stiffness (highly elastic) in polypropylene fibres; it seemed to contribute very little to the first peak strength. In this case, once the load reached the cement mortar strength, crack started to occur and then followed by a drop in loading. As a result, the first peak of PFRC was, in fact, representing the cement mortar tensile strength with a little influence from fibres.

Even though the polypropylene fibre was low stiffness, it was highly elastic and ductile. Unlike steel fibres which reacted immediately to the load at a very small deformation or crack opening, the highly elastic property in polypropylene fibre required much larger deformation or crack opening before the fibres can be strengthened and stiffened enough to response to the load. As a result of this, the recovering of load was found late in the post-peak response of PFRC.

Another important point that should be noted here was that the rate of load recovery after the peak was found to be quicker with increasing fibre content. The increasing fibre content increased the numbers of fibres intercepted at the fracture surface; the larger numbers of fibres helped on faster strengthening and load recovery. At 5% volume fraction which was the highest fibre content using in this study, the bond strength was large enough that the load recovery started immediately right after the peak with a little small dropping of load.

On conclusion, the polypropylene fibre did not seemed to contribute on the strength, they were rather contribute more on the toughness (or ductility) of the post-peak response.

3.3 Fracture Energy (Toughness)

Theoretically, fracture energy is defined as the amount of energy absorbed by the specimen up to fracture or a certain reference point (deflection or deformation). For a given load-deformation curve, the fracture energy can simply be calculated by the area under the curve.

In this study, the fracture energy up to 2, 5, and 10 mm of deformation (FE-2, FE-5, and FE-10, respectively) was calculated; the results were given in Figure 5. It must be noted that due to the brittleness of plain cement mortar, it failed mostly at the small deformation (around 1 mm); therefore the fracture energy of plain cement mortar specimen was calculated up to the peak. Comparing between plain and PFRC, the fracture energy at the small deflections (i.e., 2 mm) of these two cement mortar types were not different much. As mentioned before the first peak was, in fact, the cement mortar crack strength, since the cement mortar used here had the same strength, the area under the curve at the small deflection appeared to be in the same range.

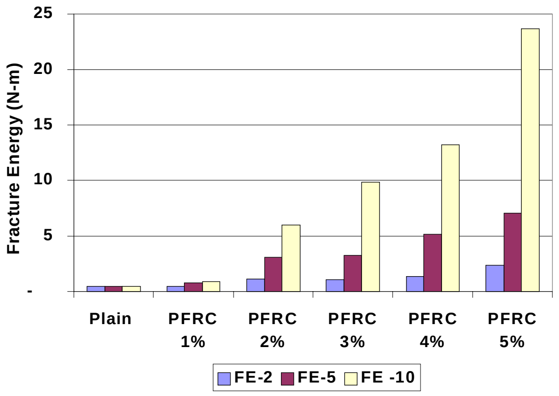

Figure 5 Fracture Energy of PFRC and Plain Cement Mortar.

In addition, polypropylene fibres were a very ductile material and because of their high elastic, they seemed to react to the load slower. This meant that the specimens were required to have quite a bit of deformation before the fibres could be strengthened and stiffened enough to react with the load. As the result of this, PFRC was not quite effective in absorbing energy at the small deflection and hence, the fracture energy was found to be similar to plain cement mortar.

However, at the large deformation (i.e., 10 mm), the PFRC appeared be more effective in term of absorbing the energy. Once the elongation was sufficiently enough, the fibre then started to react and began to absorb energy.

4. Conclusions

1. The tensile behaviour of PFRC was found to be different depending on the content of fibre.

2. Plain cement mortar because of its brittleness, it failed at a very low deformation. After the first peak, load drop to zero immediately. There was no sign of load recovery.

3. After mixing with polypropylene, the behaviour of cement mortar changed dramatically. The response of PFRC appeared to be more ductile with multiple-peak response. The load started from beginning up to the first peak, then dropped, and followed by the recovery of load by fibre bridging across the cracks.

4. However, because of its low stiffness, polypropylene fibre seemed to react to the load slower. It took a bit of deformations to get the polypropylene fibre to start gaining some loads. As a result, PFRC was not efficiently in term of carrying load and absorbing energy at small deflection (results were similar to plain cement mortar). However, later at the large deformation, once the fibres started to get strengthened, the load recovery began. Hence, the typical responses of most PFRC were found to be double-peak responses. The second peak happened late at large deformation was solely contributed by the fibres itself.

5. Acknowledgement

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