The Development High Strength of HDPE Fiber Reinforced Cement Mortar

Trithos Kamsuwan[1,*]

[1]Department of Civil Engineering, Faculty of Engineering, Siam University, Bangkok 10163, Thailand

*ICCAEE (Phone: + 66 081 934 2441; Email: skamsuwanl@yahoo.com)

Abstract:

This research evaluates the effect of melt spinning ultra-draw HDPE fiber using as the reinforced material in cement mortar. A whole set of experimental data were created reference to the efficiency of using HDPE fiber reinforced on the tensile and flexural properties of cement mortar with different high drawn ratio of HDPE fibers. The fiber with the different drawn ratio10x (d10 with E xx), 25x (d25 with E xx), and 35x (d35 with E xx) were used and the stress – strain displacement relationship behavior of HDPE short fiber reinforced cement mortar were investigated. It was found that the high drawn ratio of HDPE fiber show more improved in tensile strength and toughness than the low drawn ratio of HDPE fiber when reinforced in cement mortar.

Keywords: High Strength, HDPE, Fiber, Reinforced, Cement

1. Introduction

Fibers have been used as reinforced materials. The addition of fibers to a cement matrix is to bridge discrete cracks and binder the fracture process through an increase of the fracture energy. A variety of fiber materials such as nylon or polypropylene have been developed for the fiber reinforced cement material. Synthetic fibers are man-made fibers obtained from the petrochemical and/or textile industries. Initial attempts on using synthetic fibers (nylon, polypropylene) were not as successful as those glass or steel fibers [1, 2]. However, better understanding of the concepts behind fiber reinforcement, new methods of fabrication, and new types of organic fibers have led to an improvement of reinforce cement composite [3, 4].

Many synthetic polymer fibers such as polyethylene (PE), polypropylene (PP), polyethylene terephthalate PET), polyvinyl alcohol (PVA) have been incorporated in reinforced cement based matrices. The main problems of the polymer synthetic fiber reinforced cement are the lower tensile strength. The high density polyethylenes (HDPE), a linear chain polymer with a broad molecular weight distribution can be orient into a high strength fiber [5]. There are two processes for producing the high strength fiber including melt-spinning and gel-spinning processes [6].

In this work, the using high strength HDPE fiber prepared from the high draw ratio melt spinning technique. These method can be increase tension strength in fiber depend on the high draw ratio. The properties of ultra draw HDPE fiber are high tensile strength and high elastic modulus.

Considerable research, development, and applications of fiber reinforced composites material are taking place throughout the world. Industry interest and potential business opportunities are evidenced by continued new developments in fiber reinforced construction materials. These new developments are reported in numerous research papers, international symposia, and state-of-the-art reports issued by professional societies. The ACI Committee 544 published a state-of-the-art report in 1973 [7].

This research has the objective to study the development high strength of HDPE fiber reinforced in cement mortar and investigate the behavior of high strength of HDPE fiber effected on the tensile and flexural strength with fiber reinforced cement mortar.

2. Experimental

The experiment investigation focused on developing high tensile strength HDPE fiber and testing the behaviors of HDPE fiber reinforced in cement mortar. High density polyethylenes (HDPE) employed in the present study were 5000S from PTT chemical Public Company Limited. The fiber was prepared by a Randcastle monofilament line as show in figure 1. Fiber was prepared by 2-step method. Extruder temperatures were set at 120, 180, 190 and 215°C for zone 1, 2, 3 and die, respectively. As-spun fiber was spun at a screw speed of 2.2 rpm, or otherwise stated. The fiber was allowed to cool in air. The as-spun fiber had a diameter of about 500 µm. The as-spun fiber was drawn to different draw ratios with two sets of rollers through a glyceral bath set at 115°C. Draw ratio was calculated from the ratio of the speed of the follower to leader roller. Tensile testing was carried out at room temperature with sample gauge length of 50 mm and a crosshead speed of 25 mm/min. The properties of ultra-draw high ratio HDPE fibers as show on Table 1.

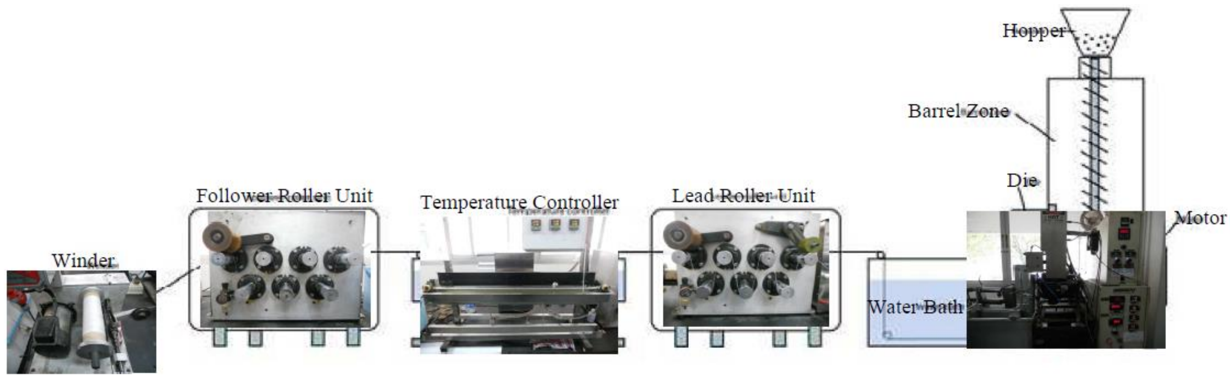
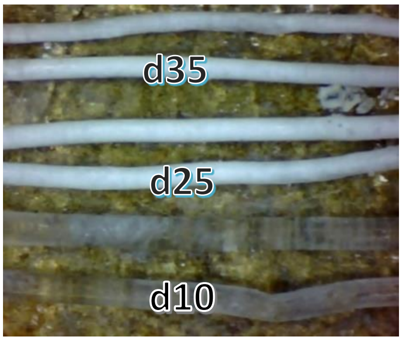


Fig. 1: Shcematic diagram of a Randcastle monofilament line employed in the study

Table 1 Properties of Ultra-draw high ratio HDPE fiber

HDPE	d10	d25	d35
Length(mm)	20	20	20
ϕ (mm)	0.202	0.172	0.148
Aspect ratio(l/d)	99	116	135
σ (GPa)	0.50 ± 0.06	0.86 ± 0.08	1.05 ± 0.10
ε (%)	20 ± 0.95	5 ± 0.58	4.5 ± 0.60
E (GPa)	6.9 ± 1.06	24.9 ± 1.80	34.5 ± 2.67
Roughness, R_a(nm)	8.36±0.1	25.68±0..28	50.31±1.04
τ (MPa)	0.563±0.07	0.914±0.01	1.015±0.10



The mix proportions used in this study were applicable to cement mortar (the standard mortar shall be one part of cement to 2.75 parts of graded standard sand by weight and water/cement ratio 0.7). In this research, the following mixing procedure was used for all mixes specified in standard specification for mortar cement, ASTM C1329M-12[8] except for the procedure of addition of fibers. First, cement and sand were mixed for approximately 5 minute. Then 50% of the mixing water was added and the mixture was mixed for 1 minute to allow for water absorption. Next, the remaining water was added. The mixing continued for another 3 minutes. All component materials except for fibers were added to ensure proper and uniform mixing. Finally, fibers were added to the mix. Altogether, the additional mixing time took approximately 5 minutes to ensure a uniform fiber distribution and to minimize fiber segregation and balling effects. After completion of the batch, the mix was placed into the appropriate molds, which were then placed on a vibrating table. The vibrating process was continued for approximately 1-2 minutes. Curing of all specimens was carried out in accordance with ASTM C192/C192M-02 (2004)[9]: after placement, these specimens covered with a plastic sheet and kept in their plastic for 24 hours. The specimens were then removed from their molds and moved to water bath, which was maintained at 100 percent relative humidity until the time of testing. Continuous curing in fresh water was contained for 28 days.

The bending test was carried out according to ASTM C 1609[10] on the 50x50x150 mm test sample. The load was applied at the rate of increase of net deflection within the range 0.05 to 0.1 mm/min until a net deflection of L/600 was reached. After that, the rate of increase of net deflection was kept within the range 0.05 to 0.2 mm/min until reaching net deflection of L/150. Test results were discarded when the crack initiated outside of the middle third of the span. In addition, the test method specified in ASTM C150[11] determined the tensile strength of cement mortar with a certain mix proportion by the use of briquette specimens. This method allows for the determination of tensile strength of a hydraulic cement mortar by casting and testing briquet specimens. Carefully center the briquet in the clips and apply the load continuously at the rate of 270 ± 10 kg/min. The tensile strength can be calculated from the maximum load and the cross-sectional area at failure of the specimen.

3. Results and discussion

The HDPE fiber used in this study is the high tensile strength HDPE obtained from melt spinning technique. The tensile properties depend on the draw ratio d10, d25, and d35 as shown in table 1 and figure 2 presents SEM photographs of highly oriented HDPE fiber. This superior property of the fiber was originated from the special process where the fiber was drawn to high drawn ratio and the polymeric molecule is highly oriented along the fiber direction. This is resulting in an improvement of the strength of the fiber [12].

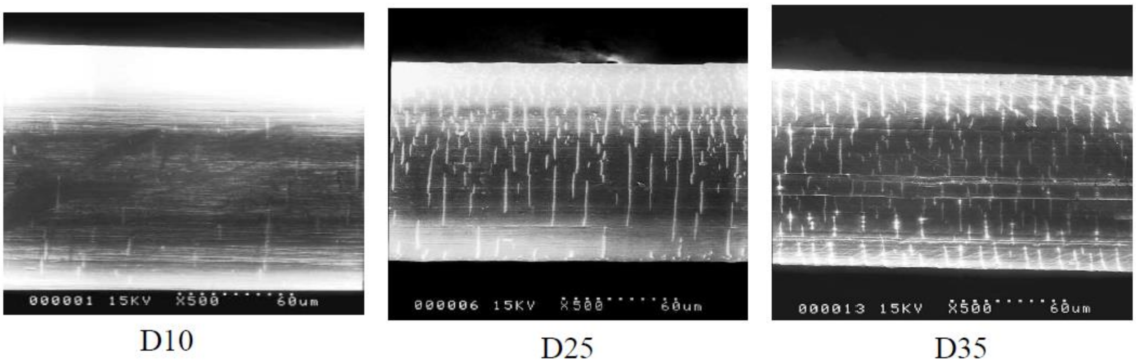


Fig. 2: SEM photographs of highly oriented HDPE fibers with different draw ratios.

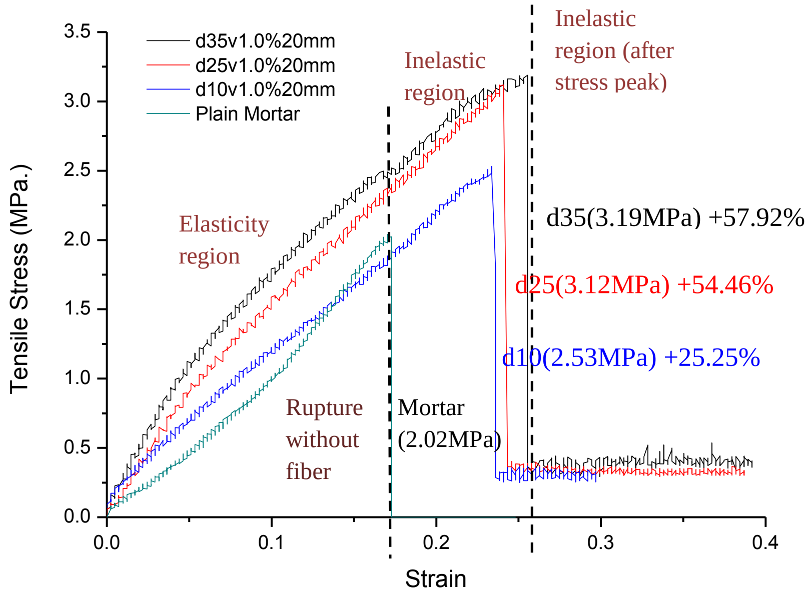
In HDPE fibers, the maximum tensile strength of the fiber at d35, d25, and d10 are 1.05 GPa., 0.86 GPa. and 0.5 GPa. respectively. In term of elastic modulus, d35 has the maximum value 34.5 GPa. higher than d25 (24.9 GPa.) 38.5% and d10 (6.9 GPa.) 500%. Most of conventional polymeric synthetic fibers have tensile strength 0.5 – 0.9 GPa. and elastic modulus 5-8.2 GPa.

In state of art report by ACI committee 544 and the other researches [13-15], we found that the factors influence on the stress and strain curve of the fiber reinforced cement (FRC) mortar comprising of the strength of fiber, volume fraction of the fiber, the length of fiber, and patterns of mixing the fibers. The variable parameters affecting the fiber reinforced cement mortar found that to compare with plain mortar, several variables can effected on the tensile stress and toughness of materials. The critical fiber volume fraction is well below 2% [16]. In this research, the parameter of volume fiber focus on range 0.5%,1.0%, and 1.5%. The parameter of fiber length in term of the aspect ratio (l/d) focus on length 5, 10, 15, and 20 mm. Most of polymer fiber reinforced cement has referenced length 5-20 mm.[17].

Efficiency of ultra-draw ratio HDPE Fiber

In order to investigate the effect of fiber draw ratio, in figure 3 and 4 are represent the ultra-draw HDPE fiber (d10, d25, and d35) in various factor of volume fiber (0.5, 1.0, and 1.5%) and different in fiber length (5, 10, 15, and 20 mm.).

In condition of increasing tensile properties in HDPE fiber by ultra-draw technique, the figure 3 used to investigate the efficiency of HDPE fiber reinforced cement mortar. The relationship between stress and strain can illustrate the behavior for reinforcing with HDEP fiber and without fiber in cement mortar. Three regions were separated to consider the mechanism of HDPE fiber reinforced



* Efficiency calculate (η) = $[(E_{xx} - E_{mortar}) / E_{mortar}] \times 100\%$

Fig. 3: Tensile stress-strain diagrams of fiber strength effective for tensile stress

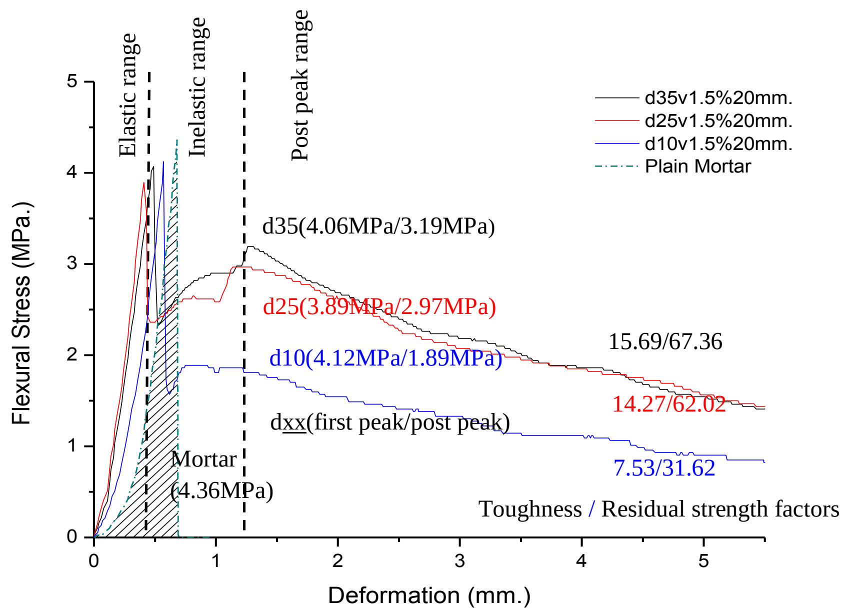


Fig. 4: Flexural stress-deformation diagrams of fiber strength effective for the toughness

First region in elasticity, for the plain mortar showed a linear relationship between stress and strain. The tensile strength of the plain mortar in this region is depending on the strength of cement matrix. Consider in HDPE fiber reinforced d10v1.0%20mm., d25v1.0%20mm. and d35v1.0%20mm., a higher elastic modulus in this region come from the efficiency of bonding between cement matrix and fibers surface. The tensile strength in these fiber are higher than the cement matrix. There for; the tensile strength in the samples HDPE fiber reinforced d35v1.0%20mm., d25v1.0%20mm., and d10v1.0%20mm. are higher than the samples plain mortar.

For the second region of inelastic was focus on the peak point of tensile stress, the relationship between stress and strain after the elastic region are start with micro-crack inside the sample expand to outside and rupture the structure. The sample without fiber was break down at this region, but the sample with HDPE fiber reinforced still hold a lot of micro-crack together. The efficiency of HDPE fiber d35 show maximum tensile stress, and HDPE fiber d25 show more tensile stress than HDPE fiber d10 reinforced in cement mortar.

The third region is an inelastic, higher tensile strength of HDPE fiber reinforced showed the value of tensile stress at still holding the part of sample was broken. HDPE fiber d35 have highly in tensile stress and HDPE fiber d25 have tensile stress higher than HDPE d10.

From the SEM of HDPE fiber shown in figure above, the details of surface area around the fiber in different rough area and the table 1 showed the mechanical properties of HDPE fiber. This evidence can justify that the strength of the fiber and rough surface area around the fiber can improve more efficiency of HDPE fiber reinforced cement mortar. HDPE fiber d35 has maximum tensile strength and HDPE fiber d25 has more tensile strength than the HDPE fiber d10. Also, the roughness area around surface fiber in HDPE fiber d35 has more roughness surface than the other HDPE fiber d25 and d10. These are the results from the process HDPE fiber by ultra-draw high ratio technique. This technique can improve the polymer structure of HDPE fiber to change slender ratio and character of surface area and mechanical properties of the fiber.

The behavior of HDPE fiber reinforced cement mortar

The relative stress-strain curves in tensile behavior for a high modulus HDPE fiber and a plain cement mortar are shown in figure 5. In case of the basic synthetic fiber reinforced, the cement matrix will fracture long before the fiber reaches its tensile strength since the fracture strain for the cement matrix is very low compared to the fracture strain of fiber. Once the cement matrix cracks, further behavior of the composite could be following on this.

In case of conventional polymer synthetic fiber(normally are HDPE fiber reinforced d10), after the cement matrix cracks, the load carrying capacity could drop but the composite could continue to resist loads that are lower than the peak load. When the cement matrix cracks, the load is transferred from the composite (matrix plus fibers) to the fibers at the crack interface. Hence, further load carrying comes from the fibers transferring the load across the crack. As the deformation increase, fibers pull out of the cement matrix, resulting in a lower load carrying capacity.

In case of high modulus HDPE ultra-draw fiber reinforced, after the cement matrix cracks, the fiber will start carrying the increased loads. If there are sufficient fibers across the crack, after the load carrying capacity could drop by the cement fracture then these fibers will continue to resist higher loads than the normal polymer synthetic fiber. The stiffness of the stress-strain curve will drop because of the loss of matrix contribution. The slope of the post cracking response would depend on the high modulus of fiber, the high volume fraction of fiber and their length fibers bonding to the cement matrix. As the load increase, more cracks will form along the length of the specimen.

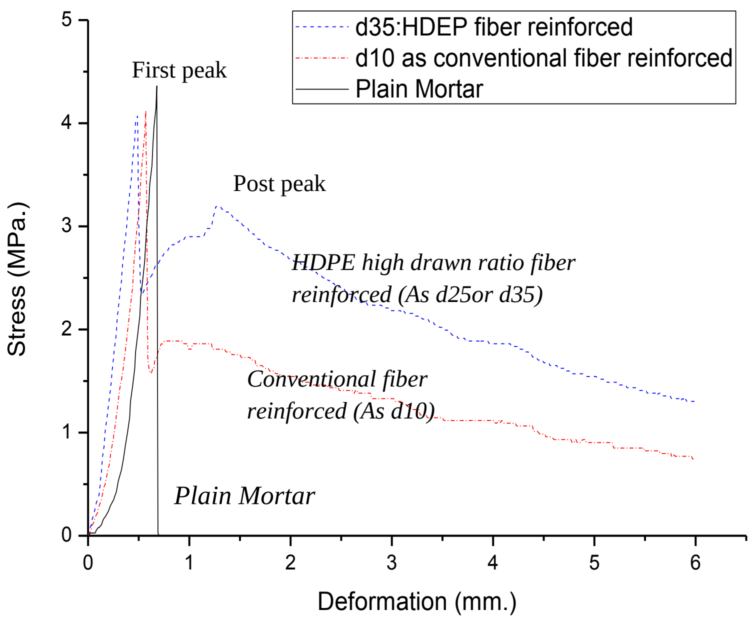


Fig. 5: Schematic stress-strain behavior of high modulus HDPE fiber reinforced cement mortar in tension

Moreover, the load carrying capacity could drop but the composite could continue to resist loads that are lower or higher than the peak load that depend on high modulus of fiber and high volume fraction of fiber. At the cement matrix cracks, the behavior of HDPE ultra-draw fiber reinforced cement mortar are similar to a normal synthetic polymer fibers but they are different in the load is transferred from the fiber is high modulus in load carrying comes from high shear stress around the roughness surface fibers transferring the load hold the crack. As the deformation more increase, fibers pull out of the cement matrix, resulting in high and higher load carrying capacity. This type of composite provides some increase in strength and provides ductile behavior. The area under the stress-strain curve is an indication of the ductility or toughness of the composite.

4. Conclusion

In this study, we developed the ultra-draw fiber HDPE to be used as reinforcing in cement mortar. The technique of melt spinning high draw ratio was used to process high tensile strength fiber. The efficiency of HDPE fiber reinforced cement mortar are verified to variable of ultra-draw HDPE fiber. The advantage of this study help to understand the behavior reinforcing of HDPE fiber in cement mortar. In term of ultra-draw fiber can increase high strength HDPE fiber by organize the polymer structure in melt spinning high draw ratio technique. They can increase tensile stress and toughness by stretch the roughness area around the surface fiber and strengthen the polymer structure fiber. The tensile strength of fiber was improved follow on high draw ratio. The fibers D35 have more maximum tensile strength than the fibers D25 and D10. The HDPE fiber D35 can improve the efficiency for reinforcing in cement mortar 81.42% at volume fraction 1.0% and fiber length 15 mm. The HDPE fiber D25 can improve the efficiency for reinforcing in cement mortar 84.46% at volume fraction 1.5% and fiber length 20 mm. The HDPE fiber D10 can improve the efficiency for reinforcing in cement mortar 44.59% at volume fraction 1.5% and fiber length 20 mm..

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