A Study of Array Direction HDPE Fiber Reinforced Mortar

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Abstract. This paper presents the effect of array direction HDPE fiber using as the reinforced material in cement mortar. The experimental data were created reference to the efficiency of using HDPE fiber reinforced on the tensile properties of cement mortar with different high drawn ratio of HDPE fibers. The fiber with the different drawn ratio 25x (d25 with E xx), and 35x (d35 with E xx) fiber volume fraction (0%, 1.0%, 1.5%) and fiber length 20 mm. were used to compare between random direction and array direction of HDPE fibers and the stress – strain displacement relationship behavior of HDPE short fiber reinforced cement mortar were investigated. It was found that the array direction with HDPE fibers show more improved in tensile strength and toughness when reinforced in cement mortar.

1. Introduction

The last four decades have seen a large number of research studies on fiber reinforced cement materials, most of which devoted to the use of metallic (steel), synthetic (polymeric), ceramic (glass), or natural (organic) fibers. In contrast, few studies dealt with the design and development of the fibers themselves. Indeed most polymeric fibers on the market today have been conceived and introduced over thirty years ago. Addressing recent trends and future directions, Fiber Reinforced Cement Composites presents new opportunities for developing innovative and cost-effective materials and techniques in cement and concrete composites manufacturing, testing, and design.

Several types of 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 [1]. There are two processes for producing the high strength fiber including melt-spinning and gel-spinning processes [2].

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. In previous researches, we found that the problem of ball and grouping during the mixing the fiber with cement aggregate can reduce the strength of their composite.

The addition of fibers to cement composites influences its mechanical properties which significantly depend on the type of fiber, the percentage of fiber and fiber orientation. For development of a new type of fiber using in cement composites, ultra draw HDPE fiber can improve more mechanical properties of the fiber reinforced matrix. High tensile strength of HDPE can transfer force and disperse stress through area of the matrix.

This research has the objective to study the effect array direction of HDPE fiber reinforced in cement mortar and investigate the efficiency of the orientation HDPE fiber reinforced cement mortar.

2. Experimental

For experimental design in this research, synthetic fibers, HDPE produced by the technique of pulling fiber high draw ratio to improve the tensile properties called high draw ratio melt spinning technique. 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.

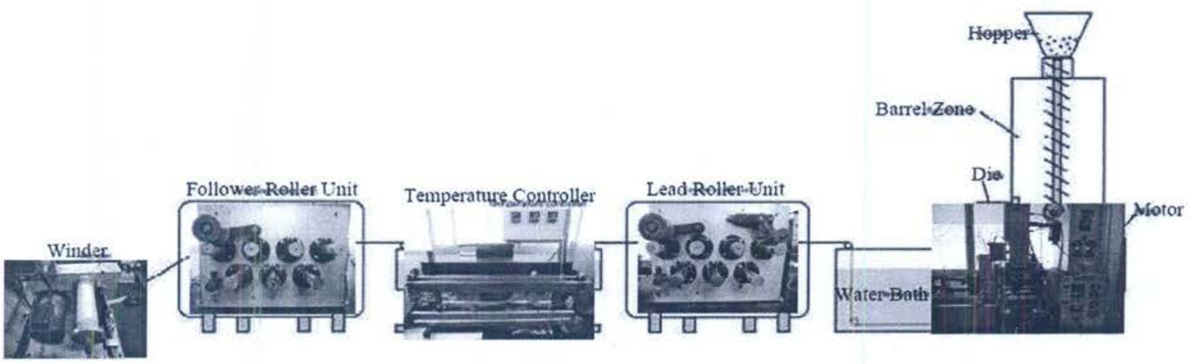


Figure 1. Shcematic diagram of a Randcastle monofilament line employed in the study

Three majors parameters were investigated including (a) tensile strength and the elastic modulus of the fiber where the fiber with different draw ratio at 25(d25) and 35(d35) will be tested (b) fiber content where percent volume fraction of the fibers will be varied from 0%, 0. 5%, 1. 0%, and 1. 5%, and (c) the length of the fibers were 20mm. The FRC recipe will be referred to as *d*x*v*x*l*x where *d* follows by the fiber draw ratio, *v* follows by percent volume fraction and *l* follows by fiber length in millimeter, for example *d*25*v*0.5*l*15 is the system with fiber draw ratio 25 having a percent volume fraction of 0.5% and the fiber length of 15 mm. This study was focused on the effect of the fiber orientation between non-oriented and partially oriented system.

In state of art report by ACI committee 544 and the other researches [4-7], 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% [6]. 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.[8].

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[9] 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)[10]: 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 test method specified in ASTM C260-01[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 d25, and d35 as shown in table 1. 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].

Table 1. Properties of Ultra-draw high ratio HDPE fiber

HDPE	D25	D35
Length(mm)	20	20
ϕ (mm)	0.172	0.148
Aspect ratio(l/d)	116	135
σ (GPa)	0.86 ± 0.08	1.05 ± 0.10
ε (%)	5 ± 0.58	4.5 ± 0.60
E (GPa)	24.9 ± 1.80	34.5 ± 2.67
Roughness, R_a(nm)	25.68±0..28	50.31±1.04
τ (MPa)	0.914±0.01	1.015±0.10

In HDPE fibers, the maximum tensile strength of the fiber at d35 and d25 are 1.05 GPa. and 0.86 GPa. respectively. In term of elastic modulus, d35 has the maximum value 34.5 GPa. higher than d25 (24.9 GPa.) 38.5%.

Efficiency of fiber direction

In table 2 showed tensile stress and elastic modulus testing compared between array and random direction HDPE fiber D35 in different volume fraction at length 20 mm. These data were presented the increasing tensile stress of array direction HDPE fiber and improving the elastic modulus of HDPE fiber when volume fraction increased.

Table 2. The tensile stress and elastic modulus of HDPE fiber D35 of array and random direction.

Direction fiber effective	Tensile Stress (MPa.)	Elastic Modulus (GPa.)
arrayD35v1.5l20	0.86	16.40
arrayD35v1.0l20	0.79	14.51
arrayD35v0.5l20	0.67	12.19
randomd35v1.5l20	0.39	13.26
randomd35v1.0l20	0.30	13.13
randomd35v0.5l20	0.27	12.06

In Figure 2, the relationship between tensile stress and strain in comparing of the patterns of fiber reinforcement and the direction reinforcement are distributed. The factors in direction of the reinforcement and distribution of the fibers effect on the increasing of the tension strength. The pattern of fiber orientation parallel to the line of force could increase the tensile stress as well. In addition, the distribution of the fiber all over cross section composited could increase the properties of the force distribution and improve a lot of the tensile stress. Furthermore, the factor of the distribution fiber would depend on the amount of fiber during mixing. The use of the excessive amount of fiber would effect on the ball and group between the fibers themselves. Of course, the efficiency of the force would be decreased.

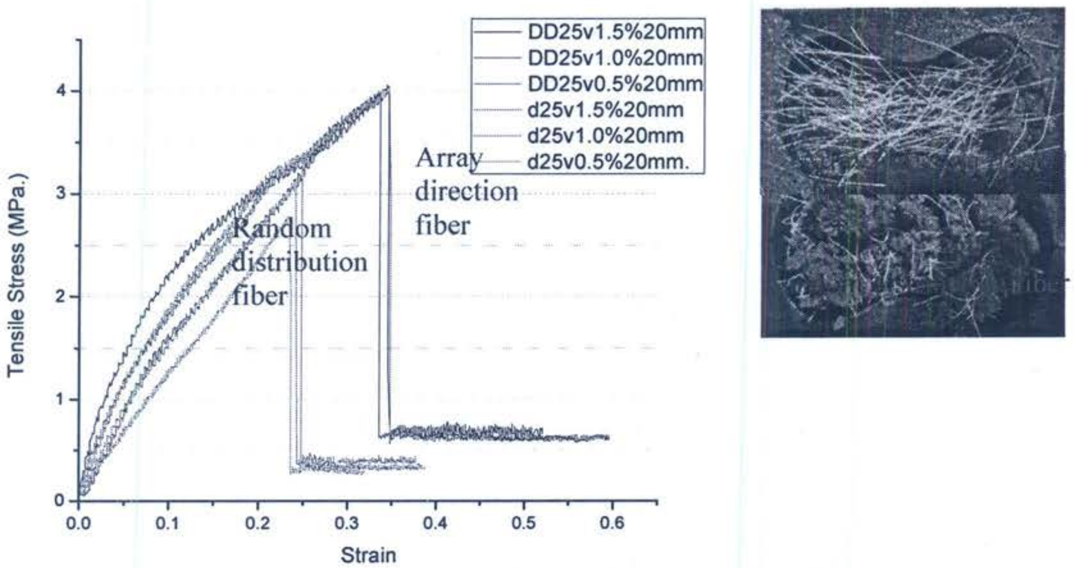
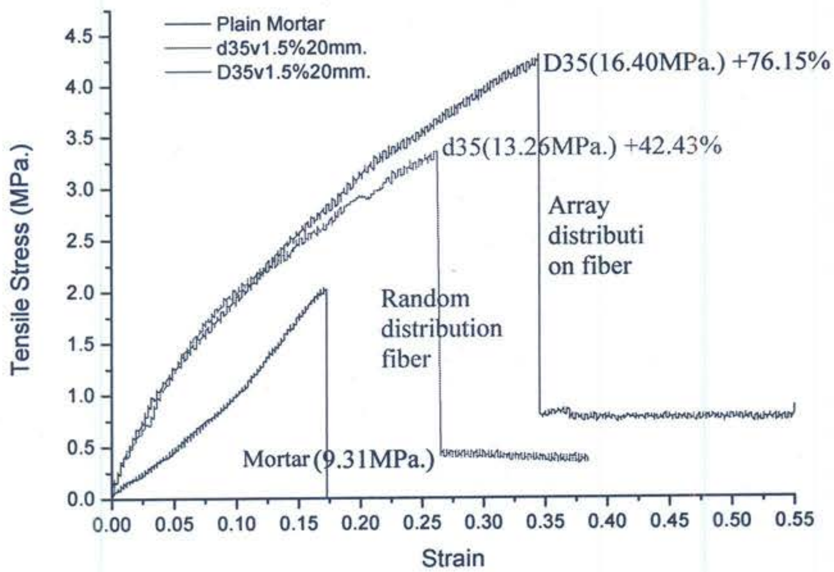


Figure 2. The stress and strain relationship of HDPE fiber D25 of the different distribution.

In figure 3 shown the relationship between stress and strain in case of the different distribution and direction of D23 HDPE fiber reinforced cement mortar. In this relationship scope of elasticity, the sample without fiber presented the efficiency of cement and sand aggregate binding to reinforced. The sample with random direction HDPE fiber reinforced presented the efficiency combine with cement, sand aggregate, and fiber for reinforcing. The value of elastic modulus and tensile stress in the sample with random distribution and direction of HDPE fiber reinforced are higher than the sample without fiber (mortar).



xx(Elastic modulus) % efficiency increase

Figure 3. The efficient of array direction HDPE fiber reinforced mortar

The consideration in this study is the efficiency of pattern to arrange the direction and distribution of HDPE fiber reinforced in cement mortar. In figure 8 exhibited the results comparing the random direction and distribution fiber with the arrangement the direction and distribution fiber. They are found that the arrangement direction and distribution HDPE fiber to be parallel with the force axis can increase the tensile stress. Basically, the structure of the sample are prepare to reinforced by align fiber and force as a same direction. They can improve the efficiency for reinforcing. Because the alignment of fiber has a good bonding between cement matrix and fiber length and can reduce the problem of group and ball with fibers.

According to the result of the sample with arrange direction and distribute of HDPE fibers is more tensile stress and elastic modulus than the sample with random direction and distribution of HDPE fibers in scope both of elastic region and inelastic region.

4. Conclusion

In this study, we developed the high tensile strength fiber HDPE to be used as reinforcing in mortar by using the technique of melt spinning high draw ratio. The efficiency of HDPE fiber reinforced cement mortar are verified to variable of ultra draw HDPE fiber, volume fraction fiber, effective fiber length, and pattern of mixing fiber. The advantage of this study is understands the efficiency of array direction HDPE fiber reinforced mortar. In term of ultra draw fiber can increase tensile strength HDPE fiber by organize the polymer structure in melt spinning high draw ratio technique. In case of arrangement fiber direction, the pattern of fiber direction and distribution are reform the behavior reinforcing of HDPE fiber in cement mortar, and can increase tensile stress. The pattern for arrangement direction and distribution of fiber helped the fiber resist force throughout the section area of fibers and solved the problem with fibers group and ball together.

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