INFLUENCE OF POLYPROPYLENE FIBERS ON MECHANICAL PROPERTIES OF DIFFERENT CONCRETE MIXTURES

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ABSTRACT

In the past few years, it has increased interest in the use of polypropylene (PP) fibers concrete, but different and often contradicting results on compression strength tests were found in literature, because compressive strength is widely used as key indicator of concrete quality and therefore needs accurate determination. Someone assumes that polypropylene fibres does not enhance the compressive strength of conventional concrete, and others suggest that the compressive strength of concrete containing polypropylene fibres could be increased with addition admixture material such as superplasticizer.

This paper researches the properties of short polypropylene fibers add to the concrete. The considered concrete was prepared under four kinds, accounting for the workability of mixed. The first mixture was the Reference (named: Ref) (without adding fibers or superplasticizer), second mixture with adding the Polypropylene fibers amounts varies from 0%, 0.9% (named: Ref + PP), (for screeds and industrial floors); third mixture includes second mixture plus superplasticizer (Addicrete BVS) (named: Ref + PP + SP). Fourth mixture includes third mixture plus PENETRON ADMIX. PENETRON ADMIX is integral crystalline waterproofing admix. Laboratory tests results shows that only the polypropylene fibers as an additive to a concrete mix has no significant effect on the compressive strength of conventional concrete but the addition of the admixture lead to increase the compressive strength. This search is different from the other in testing, we used quantitative physical aspect and mechanical aspect, almost all references listed in this paper uses only the mechanical aspects. Scanning electron microscopy (SEM) observations characterize qualitatively the voids size and the homogenous composite. Moreover, standard absorption test was used for measurement rate of absorption of water by differences kinds of concrete mixtures contain polypropylene fibers and compared the results with the reference sample. The cubic specimens were used for compression test (150mmx 150mm x150mm) and cylinder specimens (150mmx 300mm). Mechanical tests were carried out after 28-days curing times. This paper confirmed that on the basis of the performed investigations one can conclude that polypropylene fibres do not affect the compressive strength of the reinforced cement mortars. Independently on the fibres geometry and their dosage the compressive strength of the reinforced mortar does not change and is equal to the strength of the plain mortar.

KEYWORDS: *Polypropylene fibre; Concrete; Addicrete BVS; PENETRON ADMIX; Compressive strength.*

I. INTRODUCTION

Recent studies give much space to study the mechanical characteristics of reinforced fiber concrete. The fibers generally increases the quality of the surface refers to conventional concrete because they reduce the formation of the holes and surface irregularities. The water and the dirt are absorbed more slowly, resulting in a surface with more uniform appearance [1], but the fibers do not replace the traditional structural reinforcement steel or processes usual good the cement. When using fibers, it is often possible to replace the mesh with these fibers. It is known that the fibers are not easily visible on the surface of the concrete because of their fineness, also while the use of fibers increases the ductility of the concrete, that is to say its characteristics postfissuration. The advantages of the use of fibers in concrete are presented in the technical aspect where the use of a fiber-reinforced concrete is advantageous primarily in the crack control. Song et al. [2] indicated that adding polypropylene fibers to the cement composites is an effective method of preventing crack formation. Zeiml et al. [3] suggested that there is a great influence of the amount of polypropylene (PP) fibers on the spalling behavior of concrete under fire loading. Gencel et al. [4] mentioned that the split tensile strength using fibers upto 9 kg/m^3. It is found that the split tensile strength increased with increasing fiber content fibers tend to bridge the micro cracks and hamper the propagation of cracks. When tensile stress is transferred to fibers, the micro cracks are arrested and thus improve the split tensile strength of concrete [5]. In addition, the use of fibers can bring improvement of bending, tension, torsion and shear as well as the impact resistance and fatigue. A fiber reinforced concrete thus continues to bear loads after cracking. The increase in flexural capacity is achieved by increasing the resistance residual by the use of fibers. It is important to remember that the distribution uniform fiber in the mix is the essential condition for improvement the mechanical characteristics of fiber concrete. Economic aspect. The main economic benefits of fiber concrete are reduction the cost of implementation and build time; a design optimization [6]. In addition, workability of concrete decreased with increase in polypropylene fiber volume fraction, for performance effectively, the recommended rate in many of the research in fiber content up to 1% [7]. They observed that the compressive strength of concrete increased with addition of fibers. Khan et al. and Kakooei et al. [8-9] found that the samples with added polypropylene fibres of 1% and 1.5% showed better results in comparison with the others. Preti A Patel et al. [10] reported that the workability of concrete reduced with higher polypropylene fiber content. They appeared that at 0.5% of fiber content workability is high while at 1% it is medium. Polypropylenes fiber (PP) is a type of synthetic fibers derived from organic polymers and are the result of research and developments in the petrochemical and textile industries, more details of fibre production is in [11]. Polypropylene fiber fountain of water by property of hydrophobic, surface of fibers not being wet by cement paste, this leads to diminution concrete cover in the structural application. Be the introduction of fiber in concrete in many different forms such as (monofilament, twisted-bundles, fibrillated,…) depend on the length of fiber and percentages concrete admixtures which were given varying resistance to compression (of 30 MPa) and bending (of 4.5 MPa) of different rates of fiber in Portland cement concrete pavements [12]. Thirumurugan et al.[13] stated that compressive strength of concrete with the addition crimped polypropylene fibres for relative volume fractions of 0.1% and 0.3%, 56.4 MPa was observed for 0.3% of polypropylene fibres with high range superplasticizer based polymer admixtures and showed an increase in strength up to 14.6% compared to plain concrete.

Song et al.[2] observed the properties of four types of polypropylene fibers adding to mortar (fibrillated, staple fibers, monofilament, and staple fibers with crimp), can increase compressive strengths, and reduce plastic shrinkage cracks. Staple fibers with crimp are the best due to their highest fineness and good dispersion, which ensure a large quantity of evenly-dispersed fibers in mortar. The evenly-dispersed fibers prevent the expansion of micro cracks and increase crack-resistance while the mortar is still in the plastic stage. Taking staple fibers with crimp as an example, when the fiber content is 0.9 kg/m^3, the values increase by 10.3%. Consequently, all forms of fibers can effectively block plastic shrinkage cracks and achieve roughly 80% control of crack in mortar. And is best performance with 89.7% by staple fibers with crimp. Kumar et al.[14] suggested that polypropylene fiber improves the performance characteristics of the lightweight cement composites. Fiber may be used in different lengths 6mm, 12mm and 19mm and fiber proportions can be taken as 15%, 25% and 35% by cement weight in the mixture design. Addition of 35% of fiber of 19 mm length gives better result than other length and percentages. However, the compressive strength increased as the no. Of days of curing increased for each percentage PP fiber reinforcement. It is seen that the compressive strength increases from 19.6 N/mm^2 at 7 day to 40.09 N/mm^2 at 28 days. Alhozaimy [15] suggested that polypropylene fibres have no statistically significant effect on the compressive strength of concrete. Similarly Aulia [16] revealed that the use of a certain amount of fibres in concrete did not influence its main mechanical parameters detrimentally. The varying results of previous investigations led to the undertaking of subsequent studies on the dependence between Polypropylene fiber characteristics and concrete parameters [17].

The main objectives of this paper were to determine the benefits of using polypropylene fibre reinforced concrete (PFRC).

- Fabricated different concrete mixture enclosed the short polypropylene fibre.
- Observe the microstructure of plain concrete and PFRC mixes using SEM test.
- To determine size of pores of hardened concrete contain PP fibre using absorption test.
- To investigate and compare the properties of the fresh and hardened concrete mixtures using fiber.
- This paper confirmed that on the basis of the performed investigations one can conclude that polypropylene fibres do not affect the compressive strength of the reinforced cement mortars. Independently on the fibres geometry and their dosage the compressive strength of the reinforced mortar does not change and is equal to the strength of the plain mortar.

II. EXPERIMENTAL PROGRAM

2.1 Mix design

In this paper, we used two different methods of proportioning concrete mixes, where fibre characteristics and their behaviour in the cement matrix are the main object of interest, also of knowing which method is most convenient with local materials.

2.1.1 ACI mix design

The ACI Standard 211.1 is a "recommended practice for selecting proportions for concrete". The procedure is described in reference [18]. Slump values correspond to pavements and slabs type of construction of (25 – 75) mm. Approximate mixing Water 180 kg/ m3 and air content (3%) requirements for these slumps and maximum aggregate sizes of 19 mm. Aggregate volumes are calculated based on oven dry unit weights. We consider that maximum compressive strength of 30 MPa at 28 days. The percent of coarse aggregate to concrete for a given maximum size and fineness modulus of 2.4 estimated of 0.66. As volume method is the preferred method, it used to estimation of fine aggregate content, the volume of fine aggregates is found by subtracting the volume of cement, water, air, and coarse aggregate, admixture from the total concrete volume. **Table 1** shows the determined values of ACI mix proportions.

2.1.2 Dreux-Gorisse formulation

The Dreux-Gorisse formulation method determines the quantities optimal materials (water (W), cement (C), sand(S), and gravel (g) needed to make a cubic meter of concrete according to specifications loads. Several successive calculation steps are necessary for obtaining the theoretical formulation of concrete [19]. In all methods the same materials were used to mix design. Table 2 gives the determined values of Dreux-Gorisse formulation proportions.

2.2 Materials

Cement

The cement used was CEM I 52.5. The cement has a specific gravity of 2.5 with initial and final setting times 10 and 45 minutes respectively. The compressive strength measured in standard mortar at 28 days was 52.5 MPa. The physical properties are confirming to Egyptian code.

Aggregates

It used in the search will be fetched from the apse area Aljabal. Coarse Aggregates are crushed limestone from a local source was used. The Specific gravity was 2.60, Bulk density of 1600 kg/m3, oven dry three days at 110 °C. The river sand was used as fine aggregate, ssieve analysis showed that this sand size is 0-2 mm.and fineness modulus of 2.4 with specific gravity of 2.3, Bulk density of 1770 kg/m3.

Water

The water used tap water and which temperature is 20 ± 1 ° C.

Polypropylene fiber (PP)

The alkali resistance Polypropylene fibers were used; C.M.B fiber is a pure Polypropylene short cut fiber, constitute of monofilaments, fibrils bundle is 10. The fibers is mixed with the screen concrete to prevent and improve its properties, its diameter of 2mm, density 0.91 g/cm3, 15mm fiber length was used. Tensile strength 370 N/mm², modulus of elasticity 3750 N/mm² and elongation at break 11%.

Admixture (SP)
Addicrete BVS high range water reducing, superplasticiser (SP) concrete admixture was used; is a light brown ready to use aqueous solution, based on organic compounds; its density equires 1.21 kg/l; for higher compressive strength of concrete which requires big reduction in W/C ratio a dosage of 0.5% of cement weight (about 4 kg/m^3) can be used. This percent corresponds to 12% reduction in W/C ratio.

Penetron Admix (P)
An additive mixed into new concrete at the timing of batching for compete integral waterproofing, consist of Portland cement, very fine treated silica and various active proprietary chemicals, which generate a non-soluble crystalline formation throughout the pores and capillary tracts of the concrete. Thus the concrete becomes permanently sealed against the penetration of water from any direction. Dosage rate 0.8% of cement by weight. To setting time of concrete is affected by the chemical and physical composition of ingredient of concrete and climatic condition. Retardation of set may occur when using Penetron Admix. The amount of retardation will depend upon the concrete mix design and its dosage rate. However, under normal condition the admix will provide a normal set concrete. Concrete Penetron Admix may develop higher ultimate strength than plain concrete.

Table 1: Composition of concrete mixtures (kg/m^3).

Ingredient	ACI method	Dreux-Gorisse formulation
Water	180	209
Cement	400	345
Coarse aggregate	1082	1024
Fine aggregate	598	682
SP	3.45	4
W/C ratio	0.45	0.60
Apparent density	2400	2360

2.3 Manufacture of composite

The preparation of concrete mix after weight components mentioned ratios in advance where it is dry mixing of aggregates, cement and sand respectively for 3 minutes, after mixing the initial materials in the rotating mixer and adding the fibers and then is add the super plasticizer mixed with the water and are confused for two additional minutes so that the total mixing time does not exceed 5 minutes, are taking into account wetting surface of mixture before mixing. Mix Penetron Admix (0.8% of cement by weight) with water (deducted from the amount of mixing water) to form a very thin slurry for at least 5 minutes by electric mixer (see **fig 1**) add this slurry on the concrete mix after 3 minutes and then add the remainder of the mixing water with the water superplasticizer.

Fig 1: Penetron Admix mix (left) and Ref E+PP+SP+P (right).

Different mixtures cubic and cylindrical concrete samples size of 150X150X150 mm and 150x300 mm respectively have prepared, they contain 2 No. of reference (Ref A) (i.e reference of ACI mix design), 3 No. of (Ref A + PP) (i.e reference of ACI mix design+ Polypropylene fiber), 4 No. of (Ref A+PP+SP) (i.e reference of ACI mix design+ Polypropylene fiber + super plasticizer), 2 No. of (Ref A + PP + SP + P) (i.e reference of ACI mix design + polypropylene fiber + super plasticizer + Penetron Admix). For Dreux-Gorisse formulation, we prepared only two samples of cubic and cylindrical concrete samples, the nomination changes from Ref A to Ref E. For absorption test, small cubic samples sizes of 7x7x7 cm have been used for both mixtures. Specimens have removed from the mold after 24h and they were immersed under the water of 20°C, time curing 28 days.

III. TEST METHODS

3.1 Determine physical properties of composite

3.1.1 Scanning Electronic Microscopy observations (SEM)

SEM was performed on samples pre-conditioned at the environmental test conditions [temp. = 23°C & R.H. = 57%]. The test requirements were conducted to ISO/IEC 17025, observations were made on fracture surfaces and concentrated on the fibre–matrix interface. **Fig 2** shown the cubic reference sample (Ref A); cylinder samples (Ref A+PP+SP+P) and (Ref E+PP+SP+P).

Fig 2: Control Sample and Penetron Admix Samples.

SEM pictures (3.a) shows general morphology for cube control sample (Ref A) at magnification of 1000X. The figure clears the separation between the aggregate and cement bender. Image (3.b) shows the morphology for control sample with magnification of 5000X. These magnifications of the sample clear the big void through the cement bender. Image (3.c) shows morphology for control sample with magnification of 10000X. It is clear from the figure that the void sizes range between 800nm and 1500nm.

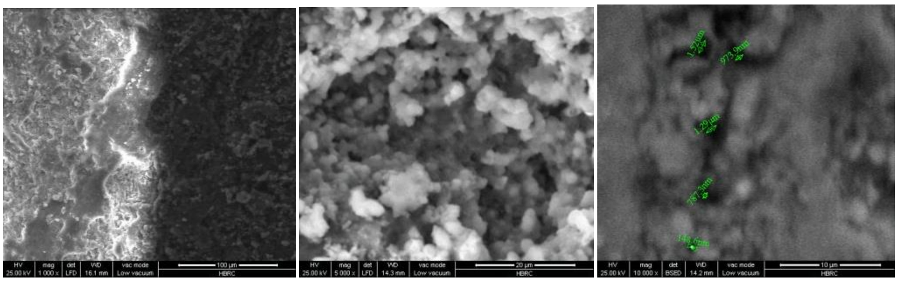


Fig 3 : Close up SEM pictures of Ref A (a) at 1000X; (b): at 5000X; (c): at10000X.

Image (4.a) shows general morphology for cube sample (Ref E+PP+SP+P) at magnification of 500X. The figure shows good contact between the aggregate and cement bender. Image (4.b) shows the morphology for cube sample with Penetron Admix with magnification of 5000X. The figure shows the presence of penetron crystals between the cement bender. It is clear from the figure that the void sizes range between 424nm and 1007nm.

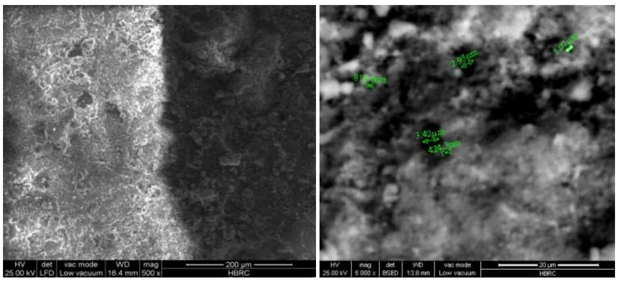


Fig 4: Close up SEM pictures of Ref E+PP+SP+P (a) at 500X; (b): at 5000X.

Image (5.a) shows general morphology for cylinder sample (Ref A+PP+SP+P) at 200X. The figure shows good contact between the aggregate and cement, it shows cracks in sand granules due to the cutting of the sample. Figure (5.b) shows the presence of penetron crystals between the cement particles at 5000X. It is clear from the figure (5.c) that the void sizes range between 315nm and 1370nm at 5000X.

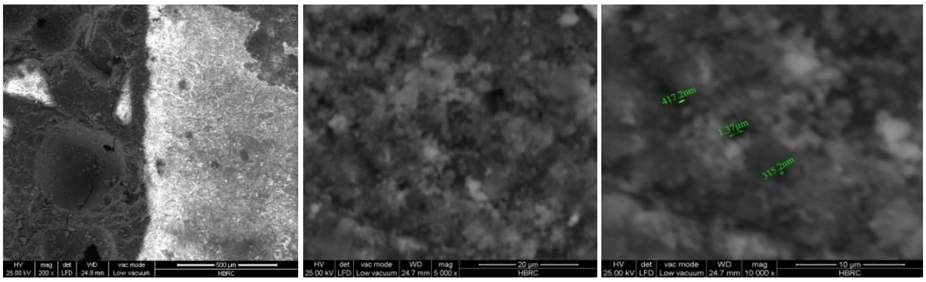
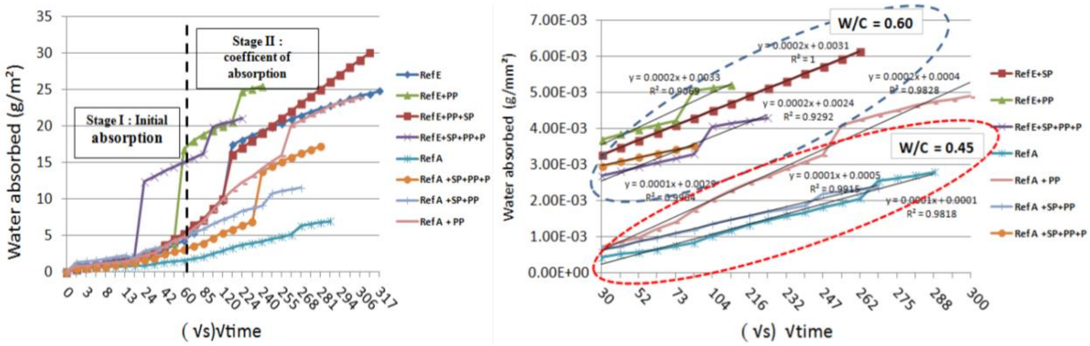


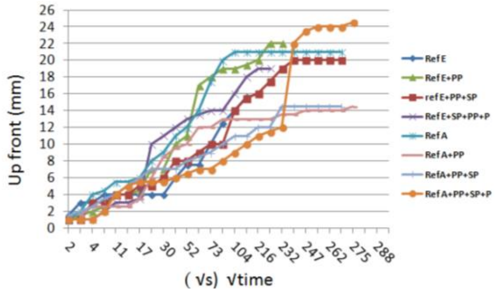
Fig 5: Close up SEM pictures of Ref A+PP+SP+P (a) at 200X: Image (b): at 5000X; (c): Morphology at 5000X.

3.1.2 Absorption test

In order to study the absorption of water of concrete after 28 days of curing, we have used water absorption test according to NF P10-502. One side of the sample plug is placed in contact with a body of water to 5mm deep and the amount of water absorbed is determined by measuring the mass variation of the sample and up front [20]. The only precaution to take is to remove the film of water retained on the underside of the sample, before each weighing, using a paper towels [21]. The amount of water absorbed every 5 sec to 45 min and then each one hour. The results of the absorption kinetics are set by two parameters following: by the height of capillary imbibitions forehead z (t); by the amount of water absorbed per unit area Dm (t) / S. **Fig 6.a** shows that water absorption is random, the first part of the curves between 0 and 1h reflects the filling of the large pores, is instable, expressing the change in z (t) and Dm (t) / S as a function of the square root of time. Specimens of W/C = 0.60 doesn't augment linearly than specimens of W/C = 0.45, both stages have roughly a linear trend. We can characterize these larger pores from the initial absorption (Amount of water absorbed between 0 and when curve becomes linear; this part corresponds to the slope of the line (removes the non-linear part of **fig (6.a)** and dividing the mass increase on the surface area of the specimens, **fig (6.b**), it will be characterized by A_{bi} coefficient (g.mm^{2}.s$^{-1/2}$). Maximum coefficient of absorption of 0.0002 g/mm.s$^{-1/2}$.This second parts of the curves (6.a) which extends beyond non linear part characterizes filling internal capillaries; this filling process is larger capillaries to the finer. The slope of the line in that part characterized by [22] the coefficients of absorption. **Fig 6.c** shows that up front measurements increase with square root of time almost linearly until filling larger pores and it becomes stable with the time, the water does not rise until the end of the sample.



(a) Mass increase vs. square root of time. **(b)** Slope values (g/mm²/s-$^{1/2}$).



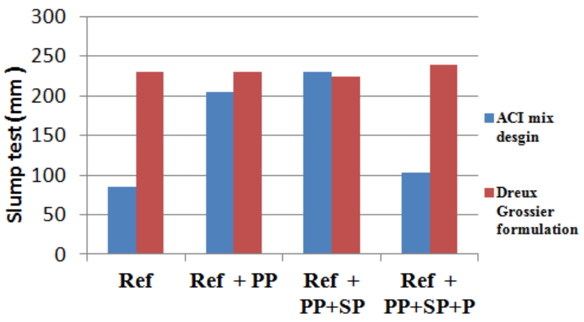
(c) Up front vs. square root of time.

Fig 6 : Absorption test results.

3.2 Determine mechanical properties of composite

3.2.1 Fresh concrete

Standard slump test according to ASTM C143-90a has used, add admixtures and PP lead to increase slump values compared to Ref but it remains liquid for Dreux- Gorisse concrete. Add Penetron diminished the workability of concrete because it absorbs the water, contrast to Ref +PP for ACI method, but no influence in second method because concrete liquid and Penetron in saturated stage, can't adsorbed more water, see **fig 7**. [23].

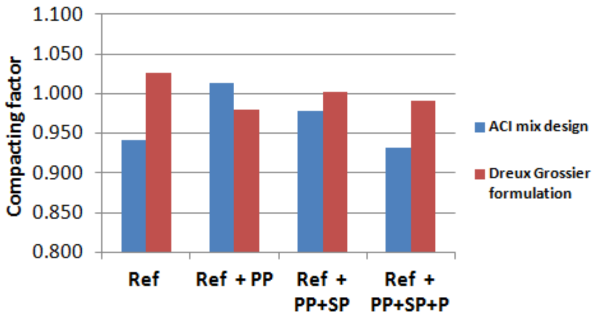


Ref A+PP+SP+P

Ref E+PP+SP+P

Fig 7 : Slump test of ACI mix design and Dreux Grossier formulation.

Compacting factor test according to ACI 211.3-75 used to determine the workability of two methods. Add PP gave maximum workability for ACI method and with second mixture workability of Ref E is maximal. But this increased isn't larger because all values approach from 1, see **fig 8**. It is clear that the compacting factor with the second mixture is more than the first method because W/C = 0.60 and leads to a more liquid mixture in all the second.



Ref A+PP+SP+P

Fig 8 : Compacting factor of ACI mix design and Dreux Grossier formulation.

3.2.2 Hardened concrete

Compression test was performed on cube and cylinder respectively at uniform rate using the 2000 kN compression testing machine, speed of deformation 5kN/min, according to ASTM C470-93 and ASTM C39-86. It is seen from **Table 2** that for controlled cube, the compressive strength reaches 49.6 N/mm2 for ACI mix and 35.51 for Dreux- Gorisse formulation at 28days.

Table 2: Compression strength of PP fibers and add admixture.

Type of concrete	ACI method		Dreux Groisse formulation	
	σ	accuracy	σ	accuracy
	MPa	MPa	MPa	MPa
Ref	45.42	0.251	30.22	0
Ref + PP	39.91	1.896	29.12	0.502
Ref + PP + SP	49.60	3.476	35.51	1.509
Ref +PP +SP + P	47.42	1.320	33.71	0.094

Compression test on Ref A

Compression strength of cylinder specimens of 31.77 MPa (approached of compression standard concrete) but elastic modulus measurement was 16.17 GPa (The modulus was below the specified value of 30N/mm² for conventional concrete as indicated in ASTM Code).

IV. DISCUSSION

From the compressive test results, it could be clearly found that PP fibers when used as a concrete additive can affect on concrete strengths with decreasing the compression strength when compared to conventional concrete mix. The addition of polypropylene fibers to plain concrete reduces its compressive strength from 45.42 MPa to 39.91 MPa with ACI method, from 30.22 MPa to 29.12 MPa for Dreux-Groisse method, see **table 2**. It is important to note that these reductions in plain concrete strength aren't higher when we used the superplasticizer BVS about 4 MPa. Higher compressive strength of (Ref A +PP + SP) specimens is 49.6 kN/mm², an enhancement in compressive strength compared to control sample occurs for the PP fiber concrete with W/C = 0.45. This research suggests that the compressive strength of concrete containing PP fibres (0 – 0.9%) is less than that of plain concrete. Other studies found that by using low volumes of 0.1% of PP to concrete didn't increase compressive strength. Verma et al. [24] showed that plain concrete has 27 MPa of compression strength and they used PP fibres (0-0.4%), estimated maximum strength reached to 26 MPa for concrete with 0.2% polypropylene fibre, and other PP percentages reduced this strength lowering than 25 MPa. Mindess et al. [25] from their experimental investigations observed that with using 0.5% PP fibres, the compressive strength could be increased by as much as 25%. Richardson, 2006 [26] founded that with 0.9 kg/ m^3 (normal dose of PP) a drop in average compressive strength of 1.17 MPa, and maximum compression strength of plain concrete 20 MPa. They assumed that the addition of monofilament polypropylene fibres into the cement is that approximately 30 million fibres per m^3 will provide 30 million breaks in the bond between cement and aggregates and this inclusion represents a large surface area of material breaking the cement bond for proportionally low weight inclusion. SEM observation appeared hydration of Portland cement and no remark on bond between fibre/ aggregares. It can be observed that workability of fresh concrete increased with inclusion PP fibres, we mentioned that affect PP is on fresh concrete than hardened concrete. With increased W/C no significant affect on the workability can observed. The reduced compressive strength was thought to cause by the inclusion of the fibres in the matrix cement of the concrete. Richardson, 2005 [27] reported that low bond strength is form breaks in the CSH bond between the cement and the surrounding aggregate. The performance of polypropylene fibers in the concrete mixture can be attributing to generation a good distribution with aggregates which enhances mechanical properties of the mixture. **Fig 9** shows that correct failure of cub specimens according to ASTM standard and no visual observation of PP fibres, they well distributed into cement matrix. From the experimental investigation carried out, it was observed that when fibers are used in concrete it doesn't enhance both the compressive strength of concrete.

Fig 9 : Compression strength of cub specimens, Ref A+PP+SP(left), Ref E+PP+SP (right).

V. CONCLUSION

1. SEM observation doesn't appear anything on distribution polypropylene fibers and reduce the voids related to introduce Penetron Admix.
2. Polypropylene fibers can be reduce the water absorption only with addition an admixture even W/C = 0.45; Ref A gave approached behavior such as Ref A+PP+SP+P, for Ref E and Ref E+PP+SP+P, the behavior are totally different and Ref E and Ref E+PP+SP are shown the same masse increased.
3. Workability of concrete increases with increase in polypropylene fiber volume fraction, but no influence with W/C = 0.60. However, higher workability can be obtained without the addition of Penetron Admix.
4. No gain in compressive strength was achieved for polypropylene fibre with W/C = 0.60 %. Thereafter use 0.9% of fibre by volume has marginally reduced the compressive strength to about 5.5 MPa (12% of plain concrete) with W/C = 0.45 %.
5. Polypropylene fibers can be enhanced the strength of concrete only with addition of supplementary material such as superplasticizer.
6. Polypropylene fibers reduce stiffness of Ref E+PP+SP+P; elastic modulus reduces to 47% than conventional concrete.
7. The failure of cube specimens was agreed to ASTM C470-93 (correct failure).
8. Little influence of PENETRON ADMIX on compression strength, it increases plain concrete to about 4%; but it leads to reduce the voids size as shown in SEM images.

VI. SCOPE FOR FUTURE WORK

From the above results it is observed that addition of Polypropylene fibres in mortar doesn't increase compressive strength compare to plain concrete; one reason is due to low bond strength from microstructure hydration. So we try to develop previous point by study the interface pp fibre/ cementitious matrix properties. And we found that addition some chemical admixture as Penetron Admix tries to improve the composite strength, and then we incorporate other products as fly.

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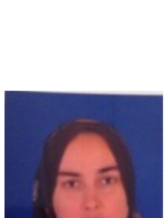

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