Effect of Hybrid Polypropylene - Carbon Fiber on Self-Compacting Mortar

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Abstract. The present work, aims to improve the properties of fresh and hardened self-compact mortar (SCM) containing hybrid Polypropylene-carbon fiber. The hybrid fiber added as a percentage 0.1%, 0.5% and 1% by volume of self-compact mortar, five different mixture of 100% - 0%, 70% - 30%, 50% - 50%, 30% - 70% and 0% - 100% for every fibers ratios (Polypropylene to carbon). The effect of hybrid fiber on some physical and mechanical properties of (SCM) was also investigated as a compressive strength and modulus of rupture, which was examined at ages of 28 days. Results showed that the best added of hybrid fiber (50 P.P-50 C.F) % increased compressive strength with ratio 32%, so increased modulus of rupture for self-compact mortar with ratio 130% at hybrid fiber (0 P.P-100 C.F) % , also indicated that the added improve hard characteristic and decrease of fresh characteristic as a flow time, mini slump flow and specific gravity, when the volume fraction 0.5% and 1% for all hybrid fiber exceeded the limits of the standard because the largest flow time is 11 seconds.

1. Introduction
Self-compacting concrete (SCC) represents a main evolution in the constructing manufacture. Its favorable features produced from an elimination of the mechanical pressure. Compared to normal vibrated cement, SCC offers plentiful advantages in the condition of technology, economy and worker health [1]. The cracking receptivity in SCC are often happened, because Self-compacting concrete (SCC) is designed by a largest volume of mortar compared to ordinary mortar [2] also less aggregate content. The increase of volume of mortar improves flow ability but it might have unlooked-for effects on time-dependent and the mechanical properties disfigurement. Drying shrinkage is known to reduce with volume of mortar [3] and the shrinkage non-restricted where, rise nearly linearly with the increase in the volume of mortar [4]. Their problem if get cracks in concrete or mortars leading from going early saturation, damage, scaling, steel corrosion and discoloration [5]. As a result of the exposure of concrete to the loads of service and during service, also in the early stages exposed to cracks that later affect the durability of concrete [6].
Fiber reinforced concrete or mortar improve strength in the service than mortar or concrete without fiber accordingly fibers finite pervasion of the cracks inside mortar or concrete [7]. So for solve that problem some researcher suggested that added fibers (as mentioned before). That added depended on many factor as kind of fiber and its volume portion has the marked influence on properties of the fiber reinforced mortars. The fiber-reinforced composites may be classified as it is function of their fiber volume fraction like low (<1.%), mild (between 1.% and 2.%), so the high volume fraction (larger than 2.%) [8]. According to many report the added steel fiber (S.F) into mortars or concrete in an amount of 1 - 1.5% by volume rises flexural strength by over to 150-200%, its tensile strength by over to 100%, so the compressive strength rises by 10 - 25% [9].

In another side some of research get better the properties of (SCM) for hardened and fresh mortars such as mechanical performance and workability, by using hybrid fiber with two or more type of fiber as reduce the brittleness of cement mass, by added of carbon fiber, calcium carbonate whisker and hybrid fiber to improve mechanical prosperities of the cement mass [10]. So investigates the mechanical properties such as density, compressive strength, toughness indices, flexural strength, and the impact-load test to all mixture of hybrid fiber (fibers-steel, synthetic fibers and palm fibers) such as 2% from volume fraction. And get to increase the amount of hybrid fibers has cause the increase of resistance the impact load, increase the load cause by first crack and post-crack strength respectively [11].

This paper aims experimentally to produce self-compacting mortar SCM by using the hybrid Polypropylene-carbon fiber to improve the properties of fresh and hardened of self-compacting mortar.

2. Experimental Works
Sixteen mixes of mortar specimens are fitted and cast. At the beginning, all mixes were designed according to EFNARC [12]. Then, three ratio by volume of mortar (0.1%, 0.5% and 1.%) are used by five percentage mix of (100 P.P-0 C.F%, 70 P.P-30 C.F%, 50 P.P-50 C.F%, 30 P.P-70 C.F% and 0 P.P-100 C.F%) for every fibers ratio (Polypropylene fiber for carbon fibers). So, The fifteen mortar mixtures contain fibers and one mixture without fibers as control mixture. Cement mortar cubes of 50 mm side length and prisms with dimensions of 40x40x160mm were used to evaluate a concrete compressive strength and modulus of elasticity, respectively. The prisms were casted and cured, according to ASTM C348 [13] and ASTM C109, to investigate the modulus of rupture.

3. Material
Cement: - Iraqi standard ordinary Portland cement was employed. The cement is tested according to Iraqi standard I.O.S No. 5/1984 [14], so the cement has achieve all a requirements. The chemical properties of this cement are showed in (Table 1).

Fine Aggregate: - Graded fine aggregate, the trading of fine aggregate as shown in (Table 2).

Fibers: - It was used two various kinds of fiber, the polypropylene fiber (P.P) and carbon fiber (C.F), the P.P made by FOSROC Company/Jordan. So the P.P fibers are 6 mm long, the physical properties as shown in (Table 3), while the second is carbon fiber manufactured by Sika Company with length of 6 mm, the physical properties of carbon fiber as shown in (Table 4).

Superplasticizer: - It was used the super-plasticizer Sikament® FFN during preparation the all mixtures in this study. It doesn’t have Ion chlorides or any other element of promoting the erosion of steel reinforcement. The weight ratio (according to the cement weight) is same in all mixtures and it is 0.4%.

4. Mixing
The mix design method used in this study was according to EFNARC [12]. Several trial mixes were done at the beginning in order to get the optimum admixture dosage and the required mechanical performances of SCM. The self-compacting mortar was fabricated by mixing 712 kg/m3 cement, 1212 kg/m3 fine aggregates, and 2.82 kg/m3 SP (0.4% of cement mass). The water-cement ratio was kept
constant to 0.45, the same above quantities were used in casting the mortars having hybrid Polypropylene-carbon fibers.

| Oxides composition          | Content % |
|-----------------------------|-----------|
| Silica, SiO₂                | 13.2 %    |
| Alumina, Al₂O₃              | 4.5 %     |
| Iron oxide, Fe₂O₃           | ----      |
| Magnesia, MgO               | ---       |
| Sulfate, SO₃                | 1.11 %    |
| Loss on Ignition, (L.O.I)   | 0.92 %    |
| Insoluble material          | 1.03 %    |
| Lim Saturation Factor, (L.S.F) | 0.8    |
| Silica, SiO₂                | 13.3 %    |

**Table 2.** Grading of fine aggregate

| Sieve size          | Cumulative passing % |
|---------------------|----------------------|
| 9.5-mm (3/8-in.)    | 100                  |
| 4.75-mm (No. 4)     | 91.32                |
| 2.36-mm (No. 8)     | 83.9                 |
| 1.18-mm (No. 16)    | 67.74                |
| 600-μm (No. 30)     | 20.4                 |
| 300-μm (No. 50)     | 2.46                 |
| 150-μm (No. 100)    | 0                    |

**Table 3.** Physical properties of polypropylene fibers

| Form                  | 100% Virgin Polypropylene Fiber |
|-----------------------|---------------------------------|
| Specific gravity      | 0.91 g/cm³                      |
| Alkali content        | Nil                             |
| Sulfate content       | Nil                             |
| Chloride content      | Nil                             |
| Air entrainment       | Air content of concrete will not be significantly increased |
| Young modulus         | (3500-4800) MPa                 |
| Tensile strength      | 350 MPa                         |
| Melting point         | 160-170°C                       |
| Fiber length          | 12 mm                           |
| Ignition Point        | 590 °C                          |
| Cement Compatibility  | Excellent                       |
Table 4. Physical properties of carbon fibers

| Details               | Description |
|-----------------------|-------------|
| Length (mm)           | 6           |
| Geometry              | Fibrillated |
| Density (Kg/m³)       | 910         |
| Diameter (mm)         | 0.02        |
| Tensile Strength (MPa)| 400         |
| Modulus of Elasticity (MPa)| 3450  |

5. Test Methods for Fresh Mortar

5.1. Mini Slump Test
That test is one of fresh mortar tests depending on measurement of spread of paste or mortar put into the cone-shaped molding. The section of cone (diameters: 100 at bottom and 70 mm at top and height: 60mm) is put in the very smooth surface and non-sucking plate, the cone filled by mortar or paste and raised [16]. The final output results are the average the diameter of two measurements made of two perpendicular directions for the fresh paste specimens, as shown in Figure (1).

5.2. Mini V-Funnel Test
The mini V-funnel test has calculating the time required to flow the volume of paste or mortar (one liter) during the nozzle. That test is oftentimes used to degree the viscosity of paste which may be linked with properties such as pump an ability, finish ability and cohesiveness. Figure (1) shown the device used in this test.

![Figure 1. Dimensions of mini-slump and mini V-funnel](image)

6. Test Methods for Hardened Mortar

6.1. Compressive Strength
According to B.S 1881: part 116: 1989 [15], compressive strength of mortar is taken by using 50 mm cubes. The electrical Compression machine are used for test with capacity of 3000 kN by speed loading
on sample 4.0 kN/second in this test. The average value each three cubes are measured to find out the compressive strength for every mixes, so the all samples tested at age 28 days.

6.2. Flexural Strength
The flexural test worked by using prisms have dimensions 40mm*40mm*160 mm, the prisms are tested depending on the specification ASTM C78. Which states that use Two points load on the samples. All samples are tested at age 28 days with the average of three samples to each mixes.

7. Results and Discussion

7.1. Fluidity
The data of test to mini-slump are shown in Figure (2). The control mixture achieved the highest slump flow values. The self-compacting mortars having hybrid Polypropylene-carbon fibers recorded mini-slump values smaller than that of corresponding control mixture, it can be note that the highest mini-slump value may be got for hybrid contain high C.F ratio compared to ratio for P.P.F as hybrid ratio (0 P.P-100 C.F) %, by about 255 mm, 280 mm, and 300 mm, respectively compared to control mixture, noted that the volume fraction 0.5% and 1% is outside the limits of the European standard (EFNARC), where the limits of the standard ranging from (240 to 260) mm. Other percentage 0.1% has within the limits of the standard ranging, so recorded mini-slump values smaller than that of corresponding the mixture composite have equal ratio for P.P.F and C.F, this may be attributed to consistency in the distribution and consensus of roughness surface for both type fibers [17].

7.2. Mini V-Funnel Test
Figure (3) shows the results of time in mini V-funnel experience. The flow time of mortars containing hybrid fibers larger than that recorded to mortar without fibers and the values increased when the fibers proportions were independent as a 100% PP-0% C.F conversely from the hybrid fibers 0% PP-100% C.F, largest values when the Polypropylene fiber proportions (100% PP-0% C.F) was higher with 39%, 86% and 121%, respectively compared to control mixture because of the surface carbon fiber was more smooth from surface Polypropylene fiber, that reduction in the viscosity of self-compacting mortars [18], also the volume fraction 0.5% and 1% is outside the limits of the European standard (EFNARC),
where the limits of the standard ranging from (7 to 11) sec, only hybrid fibers (50% PP-50% C.F) has time flow 10.5 sec that time within the standard (EFNARC) when the volume fraction equal to 0.5%. But the value of flow time for volume fraction 0.1% of all hybrid fibers has within the limits of the standard ranging.

![The relationship between mix and the flow time](image)

**Figure 3.** The relationship between mix and the flow time

### 7.3. Density

The hardened 28 days oven dry density of each kinds of mortar mixes are shown in Figure (4). From this figure, it can be observed that the dry density value for the reference mixture is more than the mortars containing hybrid fibers this reduced in density due to add fibers to the mixture, this added reduced unit weight for fiber percentage equal to 0.1% by 1.05%, 1.07%, 1.43%, 1.79% and 1.44% when the hybrid Polypropylene-carbon fibers are 100-0%, 70-30%, 50-50%, 30-70% and 0-100% respectively compared to control mixture so by 3.57%, 2.50%, 3.21%, 3.22% and 3.6% when the fiber percentage equal to 0.5% by volume. Finally, the fiber percentage equal to 0.5% by volume reduced the density compared to the reference mixture by 6.43%, 7.14%, 6.79%, 6.07% and 6.43% when the hybrid Polypropylene-carbon fibers are 100-0%, 70-30%, 50-50%, 30-70% and 0-100%., this result conforms to the requirement of ACI 213-R-03[19]. However, the reduction in the density in mortar containing hybrid fibers happened due to the low density for Polypropylene and carbon fibers [18].

### 7.4. Compressive Strength

Figure (5) Show the results of compression tests. Compressive strength is found at the age 28 days accordance to ASTM C109, as the way to quality control. The figure shows influence of fiber ratio on compressive strength, so noted that highest values compressive strength happened when the hybrid have same ratio for P.P.F and C.F on the other proportion. The figure showed that, compressive strength amount is raised because insert the fiber to sample with many fiber volume compared to the control mixture. The addition of fibers effect on cubic hardened mortars beneath axial loads, Fissures happen in microstructure of mortars and fibers decrease crack and development. Also, the compressive strength of SCM increased. All fiber fraction mixture, the maximum raised happened at hybrid ratio (50% P.P.F- 50% C.F), it was raised with 32%, 26%, and 22% for 0.1%, 0.5% and 1% fiber fraction ratio respectively, so the peak increment is for 0.1% fiber fraction (32%).
This increased in value due to the fibrous mortars sample can develop lateral tension, then that cracks begin progress. As the progress crack approaches a fiber, the interdependence at the fiber matrix interface begins because of the tensile stresses vertical to the prospective path of the development and advancing crack. All cases mentioned before up to the interface, the head of crack meeting a process of blunting and increased in compressive strength [19].

**Figure 4. The relationship between mix and the density**

**Figure 5. The relationship between mix and compressive strength**
7.5. Ultrasonic Pulse Velocity
Figure (6) shows the test result of UPV test (Ultrasonic Pulse Velocity) for SCM specimens at an age of 28 days. Results showed that the mix containing fibers reduced the velocity by increased in percentage carbon fibers about 4.5, 5.5, 7.3, 6.4 and 7.3% comparing with the reference mixture when the hybrid Polypropylene-carbon fibers are 100-0%, 70-30%, 50-50%, 30-70% and 0-100%, respectively and the fiber percentage equal to 0.1% by volume. So the ratios were 15.5, 17.3, 16.4, 17.5 and 17.4%, while the hybrid fibers are 100-0%, 70-30%, 50-50%, 30-70% and 0-100%, respectively at fiber percentage equal to 0.5%. At last the increased in the velocity by ratios 21.8%, 23.6%, 22.7%, 24.5% and 23.7%, the reason to get these results is due to the few capacities for fibers to wave transfer [20].

7.6. Hammer Test
Figure (7) shows the hammer test results. this method gives results of the rebound number, which are linked with compressive strength, give us an initial perception of the compressive strength of the SCM without the examination of the damage, where the hammer result of control mortar highest rebound number compared with SCM containing hybrid fibers, that reduced in rebound number for hammer come back to absorption and dispersion shock resulting from the hammer by fibers [20], where the resultant reduced by increased the fiber fraction were less than when the fiber fraction equal to 1% and hybrid fibers equal to (100% P.P.F- 0% C.F).

7.7. Modulus of Rupture
The average results for the flexure experience are given in Figure (8). The flexural strength trend for carbon fiber and polypropylene fiber differs when fiber increment. In general, all fiber ratio and fiber fraction, flexure strength of SCM sample increment as carbon fiber ratio increment, it can be noted: the addition carbon or polypropylene fibers slightly raises the flexural strength compared with the reference samples, increasing the total composite fiber fraction with 0.1%, 0.5%, and 1% by volume are offers an raised in the flexural strength by about 30 % for hybrid fibers equal to (30% P.P.F- 70% C.F) when the fiber fraction 0.1%, 60 % for hybrid fibers equal to (0% P.P.F- 100% C.F) at the fiber fraction 0.5% and for hybrid fibers (0% P.P.F- 100% C.F) equal to 130% when the fiber fraction 1%. This increment results foremost from the fibers intersecting vertically with cracks in the tension half of the sample.
These fibers restrict or reduce the crack face isolate by expansion the crack, so providing the extra energy-absorbing mechanism [19].

**Figure 7.** The relationship between mix and read of hummer

**Figure 8.** The relationship between mix and modulus of rupture for prism
8. Conclusions

- Added of Polypropylene and carbon fibers to the SCM mix reduced the mini-slump values, but it did not reach the minimum value for specification except when increasing the fiber percentage to 1% by volume.
- The hybrid fibers effect on flow time of SCM by increased the time, but it did not reach the maximum value for specification (12 Sec.) except when increasing the fiber percentage to 1% by volume.
- Density reduced for the hybrid fibers of SCM with increase in the proportion of fiber until it reached a ratio 7% compared to the reference mixture.
- Increased the compressive strength of SCM was contain hybrid fibers, for every fiber fraction mixtures and the maximum increment is obtained for hybridization percentage (50% P.P.F- 50% C.F), it’s was equal to 32%, 26%, and 22% for 0.1%, 0.5% and 1% fiber ratio respectively, so the peak increment is for 0.1% fiber fraction (32%).
- SCM contain hybrid fibers increased the UPV (Ultrasonic Pulse Velocity) with ratio 7%, 17%, and 24% compared to the reference mixture for 0.1%, 0.5% and 1% fiber ratio respectively, and reduced the rebound number with ratio 11%, 15%, and 19% compared to the reference mixture for 0.1%, 0.5% and 1% fiber ratio respectively.
- Added the hybrid fibers on SCM increased the modulus of rupture with ratio 30%, 60%, and 130% for 0.1%, 0.5% and 1% fiber ratio respectively for the sample compared to the reference sample.

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