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# Mechanical Properties of Ultra High Performance Fiber Reinforced Concrete (UHPFRC)

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**Abstract:** The objective of this study is to examine the mechanical properties of Ultra High Performance Concrete using steel fibers. Specimens are prepared for compressive strength, splitting tensile strength and flexural strength. For the compression test four silica fume contents and three volumes of steel fibers are used in preparing the mixes. Moreover, for the splitting tensile strength and flexural strength tests, one silica fume content, two aspect ratios and two volumes of steel fibers are used. Based on the results of this study, it is concluded that the addition of steel fibers results in a slight increase in compressive strength. On the other hand, the addition of steel fibers has a positive impact on splitting tensile strength and flexural strength of concrete.

**Key Words:** Steel Fibers; Silica Fume; Flexural Strength; Splitting Strength

## الخواص الميكانيكية للكمرات الخرسانية فائقة الأداء ذات الألياف المعدنية

**ملخص:** هدف هذه الدراسة هو فحص الخواص الميكانيكية للخرسانة فائقة الأداء بإستخدام ألياف من الحديد الصلب، فقد تم إعداد عينات لفحوصات مقاومة الضغط ومقاومة الخرسانة في الشد. وبالنسبة لإختبار مقاومة الضغط فقد تم إستخدام أربع نسب من السليكافيوم وثلاث نسب من ألياف الحديد الصلب في إعداد الخلطات الخرسانية، وبالإضافة إلى ذلك فقد تم إستخدام نسبة واحدة من السليكافيوم ونسبتين من ألياف الحديد الصلب ونسبتي إستطالة مختلفتين لهذه الألياف. وبناء على نتائج هذه الدراسة فقد تم التوصل إلى أن إضافة ألياف الحديد الصلب تؤدي إلى زيادة طفيفة في مقاومة الخرسانة للضغط بينما تؤدي إلى زيادة جوهرية في مقاومة الخرسانة في الشد.

## 1- INTRODUCTION

Attempts to achieve record compressive strengths have been ongoing for several decades, and particularly after the appearance of effective dispersants for cement systems around the 1970's. The basic target has been to decrease the porosity of cementitious materials to increase their packing density and thus their compressive strength, Wille et al. [1]. Ultra High Performance Concrete (UHPC) is one of the latest developments in concrete technology, where it refers to materials with a characteristic compressive strength in excess of 120 MPa, Hugues et al. [2]. Shihada and Arafa [3], Park et al. [4] examined the effects of changing silica fume content on the main properties of Ultra High Performance Concrete (UHPC), with particular emphasis on compressive strength. They concluded that compressive strength of UHPC increases with increasing silica fume content. Based on the results of their investigation, Bhanja and Sengupta [5] found out that silica fume incorporation results in significant improvements in the tensile strengths of concrete. Silica fume, when used, helps not only to produce ultra high performance concrete, but also it causes concrete to have more brittle structure. Therefore, improving the ductility of concrete becomes a major problem for ultra high performance concrete. Concrete with dispersed fiber reinforcement becomes a high-tech material that provides excellent performance but requires further research and development, Brandt [6]. Hoang et al. [7], Eren and Marar [8], Eren and Çelik [9], Köksal et. al. [10] and Kang et al. [11] showed that the addition of steel fibers to UHPC increases compressive and flexural strength with increasing steel fiber content. Furthermore, Rossi et al. [12] found that the fiber of UHPFRC plays a critical role in the ductile behavior of a structure till flexural failure and reported an ultimate tensile strain capacity of UHPFRC up to $5x10^{-3}$. This present study focuses on production of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) for the first time in Gaza Strip. Furthermore, mechanical properties of UHPFRC are to be investigated, with emphasis on tensile strength. Materials available at the local markets are to be used in the study. If proved successful, it is expected to be useful in conducting structural repair and strengthening of buildings damaged during the 2008-2009 Gaza Aggression.

## 2- EXPERIMENTAL PROGRAM

### 2-1 Material Properties

UHPFRC constituent materials used in this research include Portland cement which meets the requirements of ASTM C150 [13], quartz sand and basalt aggregate. The nominal size of crushed basalt ranges from 0.6 to 6.3 mm while that of quartz sand is in the range of 0.2 to 0.4 mm. The specific gravity is 2.8 and absorption is 1.48 % for basalt. For quartz sand, the specific gravity is 2.66

and the absorption is 0.62 %. Crushed quartz powder of a maximum size of 150 μm is used as ultra-fine aggregate. Silica fume that conforms to the requirements of ASTM C 1240 [14] is used. In addition, PLAST.B101P superplasticizer, manufactured by Yasmo Misr of Egypt, is used to ensure suitable workability. Due to unavailability of prefabricated steel fibers, cold-drawn stay cables are cut to the required lengths shown in Table 1.

**Table 1: Properties of steel fibers used**

| Diameter, mm | Shape | Aspect Ratio* | Yield Strength, MPa |
|---|---|---|---|
| 0.32 mm | curly | 65 | 1700 |
| | curly | 85 | 1700 |

* Aspect ratio is the length divided by the diameter

**2-2 Mixing, Casting and Curing Procedures**

Mix proportions are shown in Table 2 for the various mixes used in the study. All mixtures are mixed in a conventional rotary drum concrete mixer with a capacity of 0.4 $m^3$. At first, cement, silica fume and all aggregates are blended first and then, the mixing water and the superplactizer are added to the mixture. Finally, steel fibers are carefully scattered all over the mixture to provide a uniform distribution of fibers. After that, the specimens are prepared and covered with burlap and thin polyethylene sheets for 24 hours before being de-molded and placed in a curing basin at room temperature till testing time. Figure 1 shows one of the mixes used.

**Figure 1: One of the used mixes**

**Table 2: Mix proportions for different silica fume contents**

| Materials | Unit | Mix 1 | Mix 2 | Mix 3 | Mix 4 |
|---|---|---|---|---|---|
| **Cement** | $kg/m^3$ | 693 | 660 | 630 | 600 |
| **Water** | $kg/m^3$ | 207.9 | 198 | 189 | 180 |
| **Silica fume** | $kg/m^3$ | 0.00 | 33 | 63 | 93 |
| **Water to cement** | ratio | 0.30 | 0.30 | 0.30 | 0.30 |
| **Silica fume per cement weight** | % | 0 | 5 | 10 | 15.5 |
| **Quartz powder** | $kg/m^3$ | 300 | 300 | 300 | 300 |
| **Quartz sand (0.2-0.4 mm)** | $kg/m^3$ | 315 | 315 | 315 | 315 |
| **Basalt aggregate (0.6-1.18 mm)** | $kg/m^3$ | 460 | 460 | 460 | 460 |
| **Basalt aggregate (2.36-6.3 mm)** | $kg/m^3$ | 530 | 530 | 530 | 530 |
| **Superplasticizer** | $kg/m^3$ | 20.7 | 18 | 18.8 | 19.8 |

### 2-3 Test Specimens

The carried tests comprise of compressive strength, splitting tensile strength and flexural strength at 28 days. In order to achieve this, the following samples are prepared.

- For compressive strength tests, thirty six 100 x 100 x 100 mm cubes, shown in Figure 2, based on ASTM C109 [15] are used. For the compressive strength samples silica fume dosages of 0 %, 5 %, 10 % and 15.5 %, per cement weight, are used, while steel fibers of 0 %, 0.25 % and 0.50 %, by volume and aspect ratio of 65 are used.

**Figure 2: Some of the cubic specimens**

- For tensile splitting strength tests, fifteen 150 x 300 mm cylinders based on ASTM C496 [16] are used. A silica fume dosage of 15.5 % while steel fibers of 0 %, 0.25 % and 0.50 %, by volume and two aspect ratios of 65 and 85 are used.

- For modulus of rupture tests, fifteen 100 x 100 x 500 mm prisms, shown in Figure 3, based on ASTM C293 [17] with central point load, are used. A silica fume dosage of 15.5 % while steel fibers of 0 %, 0.25 % and 0.50 %, by volume and two aspect ratios of 65 and 85 are used.

**Figure 3: 100 x 100 x 500 mm prism**

## 3- TEST RESULTS AND DISCUSSION

### 3-1 Compressive Strength Results

Table 3 shows compressive strength results for the different silica fume and steel fiber contents. It should be noted that silica fume contents used in the study are restricted to a maximum of 15.5 %, because the superplactizer failed to produce workable mixes. The compression testing machine used in the study is shown in Figure 4.

**Figure 4: Compression testing machine**

**Table 3: Compressive strength results**

| Silica Fume Content | Steel Fibers % | Steel Fibers Aspect Ratio | Strength, MPa |
|---|---|---|---|
| 0.0 % | 0.00 | --- | 79.11 |
| | 0.25 | 65 | 79.37 |
| | 0.50 | | 79.74 |
| 5 % | 0.00 | --- | 89.49 |
| | 0.25 | 65 | 90.47 |
| | 0.50 | | 91.48 |
| 10 % | 0.00 | --- | 96.36 |
| | 0.25 | 65 | 102.35 |
| | 0.50 | | 111.07 |
| 15.5 % | 0.00 | --- | 121.50 |
| | 0.25 | 65 | 127.76 |
| | 0.50 | | 134.21 |

**3-1-1 Effect of Silica Fume Content**

The results demonstrate that the compressive strength increases with increasing the silica fume content. For samples containing no steel fibers, the maximum increase in compressive strength is about 54 % at 15.5 % silica fume content, compared with samples containing no silica fume and steel fibers. Moreover, this result is in good agreement with Shihada and Arafa [3] who reported an increase of about 58 % at the same silica fume content. In addition, Bhanja and Sengupta [5] reported an increase of 25 % in compressive strength at 15.5 % silica fume content, while Köksal et al. [10] reported an increase of 85.5 % at the same silica fume content.

**3-1-2 Effect of Steel Fibers**

The results report that the used steel fibers have a little impact on compressive strength. Maximum reported difference is about 9 % larger than strengths obtained from samples containing no steel fibers, as shown in Figure 5. Eren and Çelik [9] reported an increase of 28 % in compressive strength, while Köksal et al. [10] reported more than 100 % increase in compressive strength.

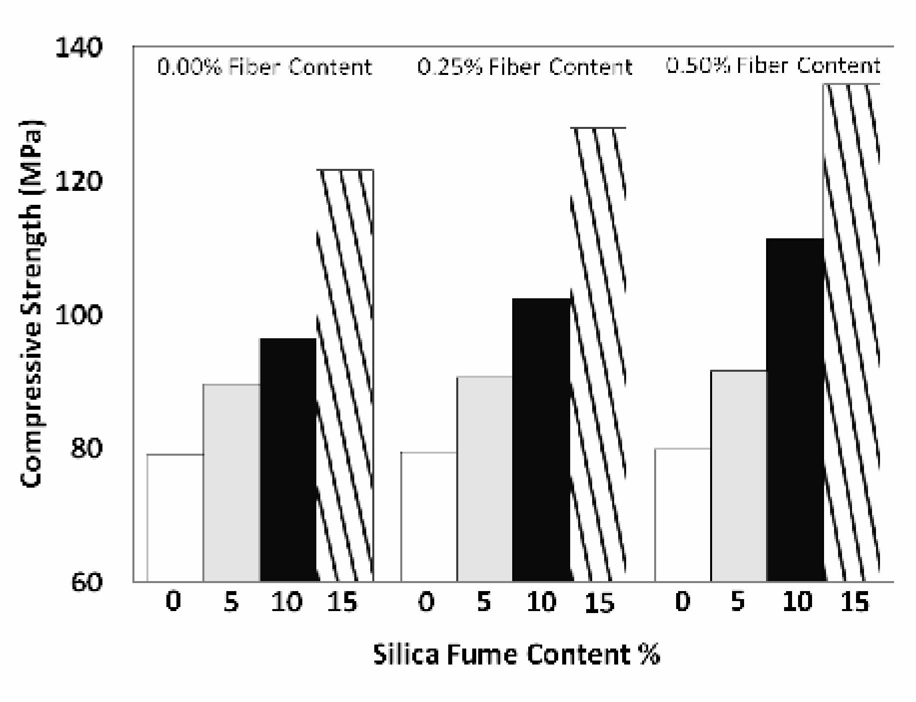


**Figure 5: Compressive strength results**

### 3-2 Splitting Tensile Strength

The splitting tensile strength results for the three used fiber contents and the two aspect ratios are shown in Table 4.

**Table 4: Splitting cylinder strength results**

| Fibers, % | Aspect Ratio | $F_r$, MPa |
|---|---|---|
| 0.00 | ---- | 5.54 |
| 0.25 | 65 | 6.54 |
| | 85 | 6.70 |
| 0.50 | 65 | 7.82 |
| | 85 | 8.25 |

### 3-2-1 Effect of Steel Fibers

For an aspect ratio of 65, the steel fibers have a positive impact on splitting tensile strength compared to the samples containing no steel fibers. The results indicate that there is about 18 % increase in strength at 0.25 % steel fiber content and about 41 % increase at 0.50 % content. For an aspect ratio of 85, the results show that there is about 21 % increase at 0.25 % steel fiber content and about 49 % increase at 0.50 % content. Eren, and Çelik [9] reported 129 % increases in tensile splitting strength, while Köksal et al. [10] reported about 92 % increase. The differences between the findings of this study and the above mentioned authors may be attributed to the differences in constituent materials, their proportions and fiber content.

### 3-2-2 Effect of Fiber Aspect Ratio

The results portray that there is a slight increase in splitting tensile strength when the aspect ratio increases, as shown in Figure 6. It is found out that the increase for the 0.25 % fiber content is about 3 % and about 8 % for the 0.25 % content. The same trend is reported by Köksal et al. [10].

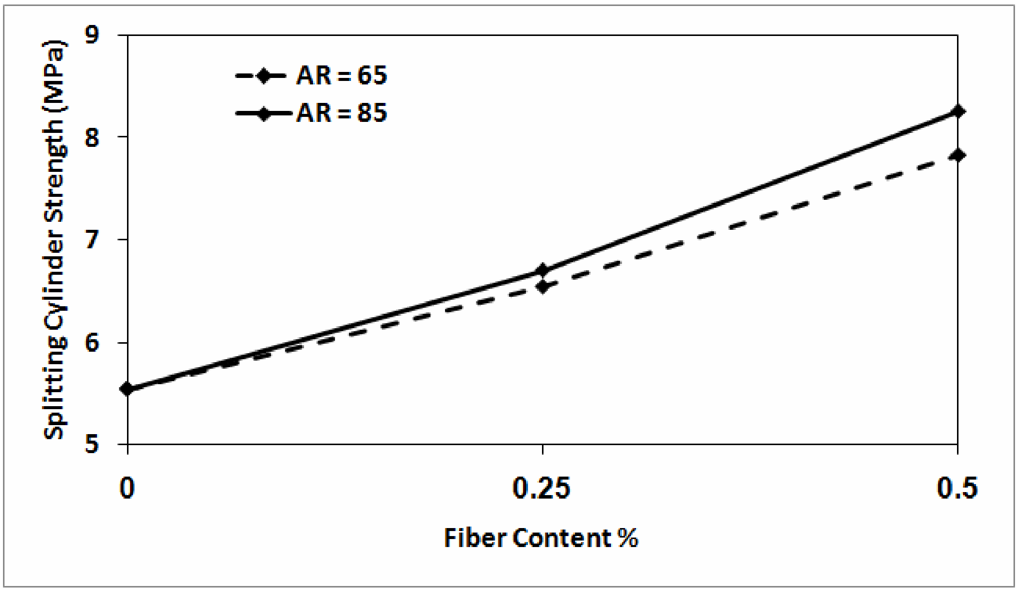


**Figure 6: Splitting cylinder strength results**

## 3-3 Modulus of Rupture Results

The modulus of rupture results for the three used fiber contents and the two aspect ratios are shown in Table 5.

**Table 5: Modulus of rupture results**

| Fibers, % | Aspect Ratio | $F_r$, MPa |
|---|---|---|
| 0 | ---- | 9.14 |
| 0.25 | 65 | 9.72 |
| | 85 | 10.14 |
| 0.5 | 65 | 11.10 |
| | 85 | 12.45 |

**3-3-1 Effect of Steel Fibers**

For an aspect ratio of 65, the steel fibers have a positive impact on splitting tensile strength compared with the samples containing no steel fibers. The results indicate that there is about 6.3 % increase at 0.25 % steel fiber content and about 21 % increase at 0.50 % content. For an aspect ratio of 85, the results show that there is about 11 % increase at 0.25 % steel fiber content and about 36.2 % increase at 0.50 % content. Köksal et al. [10] reported about 65 % increase for 15.5 % silica fume content and 1% steel fiber content.

**3-3-2 Effect of Fiber Aspect Ratio**

The results show that there is a slight increase in flexural strength when the aspect ratio increases, as shown in Figure 7. It is demonstrated that the increase for the 0.25 % fiber content is about 5 % and about 15.5 % for the 0.25 % content. The same trend is reported by Köksal et al. [10].

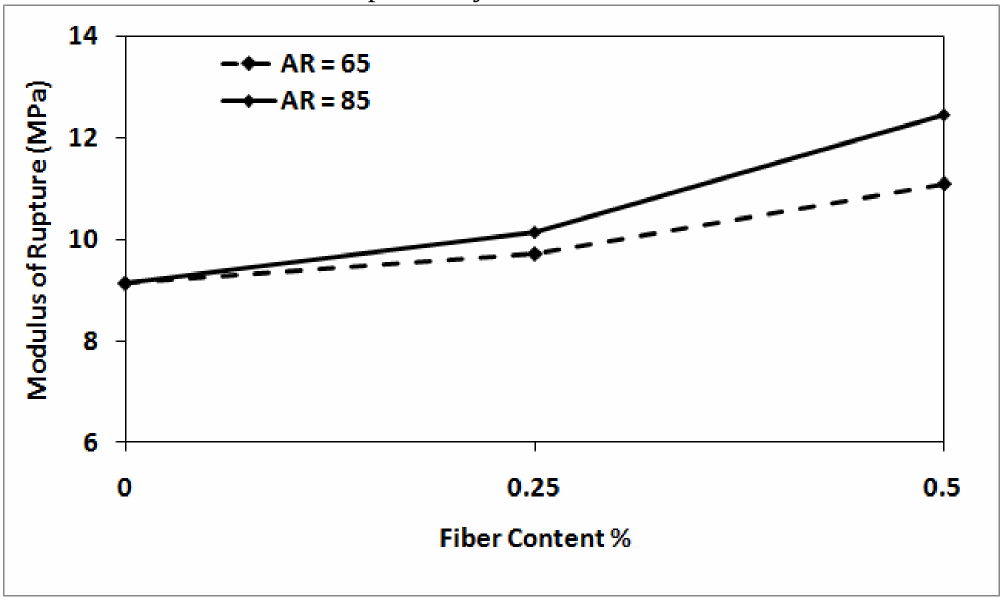


**Figure 7: Modulus of rupture results**

## 4- CONCLUSIONS

Based on the results obtained from executed experimental work, the following conclusions may be drawn out:

- Compressive strength of samples containing no steel fibers increases with increasing silica fume content. The maximum increase in compressive strength at 15.5 % silica fume content is about 54 %, compared with samples containing no silica fume. The results report that the used steel fibers have a slight impact on compressive strength. Maximum reported difference is about 9 % larger than strengths obtained from the samples containing no steel fibers.
- Steel fibers have a positive impact on splitting tensile strength, where about 50 % increase in strength is reported for samples containing 0.5 % steel fiber and an aspect ratio of 85.
- Steel fibers have a positive impact on modulus of rupture results, where about 35 % increase is reported for samples containing 0.5 % steel fiber and an aspect ratio of 85.
- The aspect ratio of steel fiber affects the modulus of rupture much more than it does for the splitting tensile strength results. Maximum reported increase in modulus of rupture results is about 15.5 % , while a maximum increase of 8 % is reported for the splitting tensile strength results.

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