Ultra-High-Performance Concrete Using Local Materials And Production Methods

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ABSTRACT

The modern architectural designs and building techniques in the construction field need new materials. Those materials have high compressive strength, such as an Ultra-High-Performance Concrete, which abbreviates by UHPC. The UHPC is suitable to use for high-rise buildings and long-span bridges. Therefore, this study investigated the ability to produce UHPCs depends on available materials and the optimum proportion of these materials. Also, the increment of the steel fiber is needed to study its effects on the mechanical properties of the UHPC. Therefore, four fraction Volume of steel fiber content has been adopted, which were 0%, 1.5%, 3.0%, and 4.5%. The results showed the ability to produce UHPC with a compressive strength reaches to 150 MPa, by using affordable materials. However, the increase of the steel fiber content would be improved the compressive strength of about 40% for the steel fiber content of 4.5% as well as the rupture stress increased to 160% for the same fraction. The results revealed that the reduction of the compressive strength reaches to 0.69 when used small molds.

Keywords: concrete, local materials, material selection, processing, ultra-high-performance.

1. Introduction

Ultra-high-performance concrete (UHPC) is a modern construction material that has been improved recently around the world. This new kind of concrete creates innovation in construction building with the advancement of material properties and technologies, which enabled the pursuit of the human challenge for constructing the height (buildings) and long span (roofs and bridges) of the structural systems [1]. Because of this kind of concrete bases on composite material, which has mechanical enhancement properties, excellent durability, and high toughness. So, this type of concrete needs for many types of research to cover all applicable usage and affordable materials.

Broadly, the UHPC is a very durable and impermeable material with very high strength offers a variety of interesting applications [2]. Therefore, it is widely using in high buildings contrary to use normal strength, which needs huge dimensions. The sustainability, impermeable, high strength characteristics contribute uses as infrastructure, namely long-span deck brigs[3].

Generally, selection material's actions are very stringent when compared with conventional strength concrete [4]. Also, very optimum proportions of ingredients are conducted to produce the UHPC mixture. Whatever the components of the UHPC are the same main ingredients of the conventional strength concrete with some modifications [4]. Ordinary cement uses in the UHPC mixture, which is the main factor that
improves concrete high-strength characteristics. Concerning aggregate, the elimination coarse aggregate process increases mixture homogenous, and remain fine aggregate gives optimum dense backing. The ultra-high-performance strength is satisfied by reduces the water continent and uses high range water reducer as a supplementary.

Further, an admixture is used, such as silica fume for a pozzolanic effect that increases the production of calcium silicate hydrate (C-S-H) and works as a micro filler to increase impermeability [5], [6]. Finally, steel fibers are embedded in the UHPC mixture to enhance the mechanical properties of the concrete members, especially the ductility [7]. Heat curing is important actin to promotes the effect of the pozzolanic effect of silica fume [8].

Richard and Cheyrezy [9] worked to develop an ultra-high-strength ductile concrete and find the optimum fraction of the silica fume, which was 25% of cement content. Then Yazici et al. [10] revealed the aspect ratio, as well as the fraction volume of the steel fiber effects, to increase the mechanical properties of the UHPC. Chang et al. [11] carried out three types of curing; 25°C and steam curing with 85°C, also the relative humidity was 95% and proved that the steam curing increase the compressive strength and splitting strength. Allena and Newtson [12] investigated three curing regimes cured by ambient temperature, immersion specimens on heat bathwater of 50°C, and exposure to dry heat 200°C by used 50mm and 100mm cubic molds. The results have been shown the third regime increased the compressive strength and increased the ductility, while the small size mold has low compressive strength.

Magureanu et al. [13] studied the influence of the curing with 2.55% volume of two types of steel fiber and without steel fiber, then remarked that the compressive strength increased for fiber-reinforced matrix within (14-16)% greater than matrix without reinforced fiber. Hoang et al. [14] depended on the stepwise optimization of particle packing density to increases the compressive strength. Pourbaba et al. [15] investigated the steel fiber content on the compressive strength.

Forgoing, The UHPC needs to investigate the suitable ingredients and its proportion, especially when need to produce from local material. Therefore, the challenge for producing UHPC, that is how to choose affordable materials and finding a proper proportion of ingredients. Since several researchers used 50mm molds to avoid using high capacity of compression machines, therefore, this study investigated the difference of the results that small molds.
2. Experimental program

2.1 Ingredients

The ingredients of materials that have been used are similar to normal concrete, with some exceptions. Cement is an important material used to produces the UHPC. There are several commercial brands of cement available in the market. The cement has a brand CRESTA 42.5R, is used to produce the UHPC.

The aggregate consists of only fine aggregates, or fine sand, which is locally known Al-Ekhaider, used. The maximum size of the fine aggregate is less than 600 Micrometers, as well as the distribution size within the tolerance limit of salt contamination. Also, the sand corresponded with Iraqi specification No.45/1984 [16].

Micro Silica Fume was used for compositions of the pozzolanic effect by increasing the production of calcium silicate hydrate (C-S-H) and as a micro filler to increase impermeability [13]. The MegaAdd MS(D) Densified micro silica of ConMix company were used, and have been tested the activation of silica fume, according to ASTM C1240 [5]. Three mixes adopted to find the best technique to use the silica fume. The first mix was achieved without silica fume. Then the second mix was achieved by added only 10% of silica fume relative to cement weight content in the mix. The final mix achieved by two techniques. The first technique by added silica fume. While the second technique by supplemented silica fume with cement. The replacement ratio of silica fume with cement is 10% weight of cement. Also, the silica fume added to a mix of 10% of cement content, as listed in Table 1. Since the third mix was obtained high compressive strength, therefore, this mix will have adopted in the present study.

| Cement Content, Kg | Sand kg | Supplementary Silica fume content(%), kg | Added Silica fume(%), kg | Water cement ratio | Superplasticizer L/m³ | 7days |
|---------------------|---------|-----------------------------------------|-------------------------|-------------------|----------------------|--------|
| 500                 | 1375    | 0                                       | 0                       | 0.484             | 12                   | 28.4   |
| 500                 | 1375    | 0                                       | (10%)50                 | 0.484             | 12                   | 41.57  |
| 450                 | 1375    | (10%)50                                 | (10%)50                 | 0.484             | 12                   | 45.68  |

The superplasticizer of the third generation was used of poly-carboxylic polymers with long chains has the commercial brands of Master Glenium 51 were produced by BASF–The Chemical Company. Four trails have been conducted to find suitable batches of superplasticizer should be replaced by water to get reasonable workability, as remarked in Table 2. the results revealed that the best w/cm ratio is 0.2 of cementitious materials.

| Cement Content, Kg | Sand kg | Supplementary Silica fume, kg | Added Silica fume, kg | W/cm | Superplasticizer, L/m³ | Slump test mm | 7days |
|---------------------|---------|-------------------------------|-----------------------|------|-----------------------|---------------|--------|

Table 1: Activity test of silica fume, kg per one cubic meter.

Table 2: Testing Results of Superplasticizer dosage (kg per one cubic meter)
Broadly, the main parameter that has been investigated in the present study to produce ductile concrete is the content of steel fiber, which also increases the compressive strength and enhancements the mechanical properties of the UHPCs [13]. The aspect ratio (length of the fiber to the diameter of the fiber) of steel fiber is about 59. However, the tensile strength of the steel fiber is about 2850MPa.

2.2 The Proportion Of The Ingredients
Finally, several trail mixes are conducted of concrete to find the best mix proportion of ingredients that is suitable and affordable to produce ultra-high-strength concrete. Table 3 consists of the final proportions of ingredients to produce the UHPC.

| Cement, kg/m³ | Fine sand, kg/m³ | Replacement Silica Fume, g/m³ | Added. Silica Fume, kg/m³ | w/cm ratio | HRWR, L/m³ | Steel. Fiber, kg/m³ |
|--------------|-----------------|-----------------------------|---------------------------|-------------|------------|---------------------|
| 900          | 1050            | 100                         | 100                       | 0.20        | 45         | 117.75, 235.5 and 353.25 |

2.3 Mixing and Placing
The mixing process of the ingredients to products UHPC is a very critical task and must be as close as possible practically. So, many trail batches should be conducted to gain a specific property, such as compression strength. Also, the finer and sticky materials need to make efforts to ensure the homogeneity of all constituent by increases the time of mixing [4], [9]. The mix beginning with dry materials and then added the mix of potable water and superplasticizer, finally added a required fraction volume of steel fiber, according to ACI committee 544R [7]. The water-cementitious ratio and amount of superplasticizer are reflected in the required strength and accepted workability of the past. Therefore, the UHPC has good workability some time considered as a self-compacted concrete SCC (for the mix without steel fiber) [9].

The procedures of mix achieved according to the specification of a high-performance concrete mixing guide [4] and reactive powder concrete guide [7]. The dry cement with dry micro silica fume is mixed firstly for 1 minute and added fine sand gradually, then added water, and sequentially with superplasticizer and mixing the mixture for 5 minutes, as explained in Figure 1.

2.4 Curing
The two main factors influenced on the set time, and hardening of any concrete are the temperature and moisture. The moisture controlled by immersion the specimen in the water for 24 hours after casting. While
the temperature was rising to increase the activity of the silica fume. The curing was achieved by immersion samples, after 48 hours of casting, in the hot bath. The temperature of hot bath was 60 °C was rising gradually when the samples cured, and continuous for 26 days, as shown in Figure 2. generally, the post-curing increases compressive strength and modulus of elasticity of UHPC as remarked by Chang et al., 2009 [11], Alinia et al. [17], and Khalil [3].

3. Results and Discussions
Three types of tests achieved compressive strength, splitting strength, and rupture strength. All specimens tested after the age of 28 days.

3.1 The Compressive Strength
The compressive strength achieved by used three sets of molds; cubic 50mm, cubic 100 m, and cylinder with a diameter of 100mm and height of 200 mm. these samples were tested by compression machine type
ELE. Four groups were tested according to steel fiber content. The first group is without steel fiber 0%, which has low compressive strength as brief in Table 4. While the second and third groups with a steel fiber content of 1.5% and 3.0%, that have a compressive strength greater than group one (without steel fiber), the increments percent due to increase steel fiber content is 19.7% and 23.5%, respectively. However, the fourth group with a steel fiber content of 4.5%, which eaches to 160 MPa. The increment of the fourth group of compressive strength is 39.7%, greater than the concrete mix without steel fiber. That indicated the content of the steel fiber increases the compressive strength, as shown in Figure 3. These results are corresponding with the results of Poubaba [15] in the same fraction volume content of steel fiber, between (1-2) %, 3%, and (4-5) %.

The compressive strength of a cubic sample of (50 × 50 × 50)mm, is less than a cubic sample of (100 × 100 × 100)mm for the same mix and same age, while the average reduction value is about (0.69). While the results by Magureanu [13] as mentioned that the reduction was 0.8 when using smaller dimensions mold. The compressive strength also varies. when used cylindrical mold (100 × 200) mm, the compressive strength of concrete reduces about (0.8) when compared with cubic 100mm mold, as listed in Table 4.

Figure 3: Compressive strength related to Steel fiber content.

Table 4: Summary of Compressive Test.

| Steel fiber Content | Compressive strength MPa. | Reduction ratio | Increment of compressive strength of cubic100. |
|---------------------|---------------------------|-----------------|-----------------------------------------------|
|                     | Cubic50mm | Cubic100mm | cylinder100 × 200 | cubic100 |                             |
| 0%                  | 84.1      | 114.5      | 0.73             | 0.80     | **                           |
| 1.5%                | 89.2      | 137.1      | 0.65             | 0.74     | 19.7%                        |
| 3.0%                | 98.5      | 141.4      | 0.70             | 0.84     | 23.5%                        |
| 4.5%                | 109.2     | 159.9      | 0.68             | 0.80     | 39.7%                        |
| Avarage             | 0.69      | 0.80       |                  |          |                              |
3.2 Splitting Test
The splitting test conducted according to ASTM C496-07 [18]. Three sets of cylindrical specimens with dimensions (200 Height×100 Diameter) are tested by using compression machine type Control. The results show that the splitting results increased when steel fiber content increased due to the tensile strength improved in the matrix of the concrete. The mixture with steel fiber content 1.5%, 3%, 4.5% is greater than mixture without steel fiber of the present of 97%, 142%, and 193%, respectively, as shown in Figure.4. Table 5 brief all results of the rupture and splitting test.

3.3 Rupture Test
The rupture or flexural strength test used to measure the indirect tensile strength of the concrete. The test adopted, according to ASTM C78[19]. The geometrical dimensions of the prism specimens were (100 × 100 × 500)mm. Four sets of the samples are used to implement that test. The modulus of rupture increases when steel fiber content increased. That increments percent are 49%, 115%, and 173% for the steel fiber content of 1.5%, 3.0%, and 4.5%, respectively, greater then mix without steel fiber, as listed in Table 5. The curve of rupture strength versus steel fiber content, as shown in Figure.5, showed the rate of percentage increment between concrete, the mix with 4.5% steel fiber content is higher significantly than others.

![Figure.4: Splitting Stress Vs. Steel Fiber Content.](image1)

![Figure.5: Tensile Stress Vs. Steel Fiber.](image2)

| Content of steel fiber | Splitting test | Rupture test |
|-----------------------|----------------|--------------|
|                       | Stress MPa.    | Increment    | Stress MPa.    | Increment    |
| 0%                    | 6.21           | **           | 9.67           | **           |
| 1.5%                  | 12.25          | 97%          | 14.42          | 49%          |
| 3.0%                  | 15.05          | 142%         | 20.74          | 115%         |
| 4.5%                  | 18.20          | 193%         | 26.39          | 173%         |

Table 5: list the Testing Results of the splitting and rupture Tests.
3.4 Modulus Elasticity

Many researchers need to find the relationship between the compressive strength of concrete and its elastic modulus (Ec). The ACI Code 318 [20], and ACI committee 363 [4] provided equations for plain concrete. Also, there were numerous researches to find a relation between stress and strain of the UHPC, as investigated by Thomas and Ramaswamy [21]. In the present study, the static modulus of elasticity conducted according to ASTM C469-07 [22]. The test of the modulus of elasticity carried out on the cylinder samples has 200mm height and 100m diameter arranged by used two rings and laser LVDT, as explained in Figure 7.

Consequently, the results indicate that the modulus of elasticity increases when steel fiber content increased, as shown in Figure 6. The modulus of elasticity of the concrete content 4.5% of steel fiber is about 90000MPa at the linear limit. However, the modulus of elasticity of the concrete with a steel fiber content of 3% and 1.5% are 78000 and 66000 MPa, respectively, while the modulus of elasticity of the concrete without steel fiber is about 50000MPa, which has been obtained from the test when calculating the average of the dividing the stress to strain at linear stage only.

Generally, the increasing content of steel fiber enhances the behavior of UHPCs and its mechanical properties. The failure mode and cracks pattern of concrete varied as steel fiber embedded inside the concrete content.

![Figure 6: Stress-Strain Curves Of UHPC.](image)

![Figure 7: Test Setup of the Modulus of Elasticity.](image)

4. Conclusion and Discussion

This study demonstrated the ability to produce concrete with Ultra-High Performance concrete, UHPC, from affordable materials. However, the process of production needs more stringent actions for choosing materials, the efficiency of the mix, and curing by a hot bath. Generally, the effect of using a different content of steel fiber on the mechanical properties of concrete briefed as follows;
1. The compressive strength increase of 19.7%, 23.5%, and 39.7%, when added steel fiber of 1.5%, and 4.5% to UHPC mix. Also, the compressive strength was affected by the shape and size of the mold. The average reduction in compressive is 0.69 when used 50mm cubic mold instead of 100mm cubic mold, while the average reduction in compressive strength is 0.8 when used cylinder with a diameter of 10mm instead of 100mm cubic mold.

2. The steel fiber content shows a significant effect on the indirect tensile strength conducted by the splitting test when compared with a concrete sample without steel fiber. However, increment percent of splitting tensile strength, when compared with concrete without steel fiber, was 97%, 142%, and 193% corresponded to increased steel content of 1.5%, 3%, and 4.5%, respectively.

3. The indirect tensile strength conducted by the flexure rupture method revealed that the tensile strength increases of 49%, 115%, and 173% with steel fiber increase of 1.5%, 3%, and 4.5%, respectively. However, the higher content of steel fiber increases the tensile strength rapidly.

4. The stress-strain curves of the under compressive test obtained that the modulus of elasticity reaches to 90000MPa for concrete has 4.5% content of steel fiber while the concrete samples have a steel fiber content of 3.0 % and 1.5%, which have a modulus of elasticity of 78000MPa, and 66000MPa, respectively. Finally, the plain concrete has a modulus of elasticity about 50000MPa, which closed to calculating the modulus of elasticity according to ACI code.

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