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# Mechanical Properties of Ultra-High Performance Fiber Reinforced Concrete

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***Abstract*— Using of ultra-high-performance-fiber reinforced concrete (UHPFRC) in structural applications has significantly increased owing to its numerous advantages compared with conventional concrete such as normal concrete (NC) and high-performance concrete (HPC). UHPFRC exhibits superior properties in terms of compressive behaviors, tensile behaviors, and durability. this paper investigate the effect of steel fiber (volume fraction and aspect ratio) on the mechanical properties of ultra-high performance concrete such as, Compressive strength, modulus of elasticity, Poisson's ratio, flexural strength and tensile strength. It is observed that mechanical properties are on higher side for 3% steel fibers volume fraction as compared to that produced from 0%, 1% and 2% fibers volume fraction.**

*Index Terms*—**UHPFRC, steel fiber, volume fraction, aspect ratio, mechanical properties.**

## I. INTRODUCTION

Many researchers around the world have developed concretes that could be classified as UHPC. Although there are differences among types of UHPC, there are also many overall similarities. The Association Française de Génie Civil (AFGC) document Ultra High Performance Fiber-Reinforced Concretes-Interim Recommendations indicates that UHPC tends to have the following properties: compressive strength that is greater than 150 MPa , internal fiber reinforcement to ensure non brittle behavior, and a high binder content with special aggregates. Furthermore, UHPC tends to have very low water content and can achieve sufficient properties through a combination of optimized granular packing and the addition of high-range water reducing admixtures [1]. UHPFRC development found its origin in the studies of Odler, Brunauer and Yudenfreund in the beginning of the 1970s. **Yudenfreund et al., (1972)** [2], they investigated high strength pastes with low w/c-ratios (w/c = 0.2 to 0.3) whose main characteristic was the low porosity leading to high compressive strengths (up to 200 MPa) and to low dimensional changes. Strength enhancement by hot pressing techniques was first applied by Roy and resulted in very high strength cement pastes with compressive strengths up to 680 MPa. **Roy et al., (1972)** [3]. With the development of super plasticizers and pozzolanic admixtures such as silica fume, two kinds of materials emerged in the 1980s: Birchall developed polymer modified cementinuos materials called Macro-Defect-Free (MDF) cements. The pores are filled by polymerization leading to a compact matrix. However, these concretes are susceptible to water and have high creep. **Kendall et al., (1983), Alford et al.,(1985)** [4,5]. Bache developed the DSP (Densified Small Particles) which use the interaction of super plasticizers and silica fume to decrease the porosity of the material and to increase the strengths. That way, he prepared the ground for modern UHPFRC development. **Bache., (1987)** [6]. However, theses high strength cement pastes and mortars are very brittle. Consequently, the addition of fibers is necessary to enhance ductility (increase of SF). Three tendencies are distinguished by **Rossi., (2002)** [7]**:** DSP with an addition of 5 to 10% short steel fibers ($l_f$ = 6 mm), commercialized under the name. the so-called Reactive Powder Concrete (RPC) with 2.5% of short slender steel fibers (lf = 13 mm), developed by Bouygues, Lafarge and Rhodia and commercialized under the name Ductal . and the Multi-Scale Cement Composite (MSCC) using a mixture of short and long steel fibers. MSCC are developed at the LCPC in France and are known under the name CEMTEC. **Collepardi et al., (1996)** [8] investigated in three sets **(i)** replacement of ground fine quartz sand (0.15-0.40 mm), (**ii**) a part of (cement + silica fume) of the cementinuos binder and (**iii**) the whole of fine sand by graded natural aggregate (max size 8 mm). Studies revealed that (**i**) there is no change in the compressive strength of the RPC at the same water-cement ratio. (**ii**) An increase in the water-cement ratio is observed, due to which there is reduction in the cement factor, and hence decrease in compressive strength. (**iii**) Flexural strength was lower when graded coarse aggregate replaced all the quartz sand. Steam curing done at 90°C and 160 °C provided lower drying shrinkage and creep strain. **Feylessoufi.A. et al., (1997)** [9] stated that xonolite is one of the most important crystalline hydrates in RPC. The heating mode studied were putting the specimen directly in the oven preset at 300°C, conventional thermo gravimetric analysis(TGA) in vacuum at a rate of 100 °C and kinetically controlled thermal curing (CRTA) technique. Results showed control rate of heat treatment at a definite water vapour pressure is required in order to get precise control of hydrate crystallization. **Garas, Kahn, and Kurtis., (2009)**[10] conducted trials to study the stress/strength ratio, thermal treatment and fiber reinforcement consequences on the tensile creep behavior, tensile strength and free shrinkage using different UHPC mixes. They concluded that usage of fibers and the application of thermal treatment decreased 14-day drying shrinkage by more than 57% and by 82%. Increasing the stress-to-strength ratio from 40% to 60% increased the tensile creep coefficient by 44% and the specific creep by 11%, at 14 days of loading. Incorporating short steel fibers at 2% by volume decreased the tensile creep coefficient by 10% and the specific creep by 40%, at 14 days. Also, subjecting UHPC to a 48-h thermal treatment at 900C, after

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initial curing, decreased its tensile creep coefficient by 73% and the specific creep by 77% at7 days, as compared to ordinarily cured companion mixes.

## II. EXPERIMENTAL PROGRAM

### *A. Materials and mix proportions*

The details of mix proportions used in this research are given in Table 1. Ordinary Portland cement type (I) with high grade 52.5N and silica fume (SF) were used as cementitious materials. The chemical compositions and physical properties of the cementitious materials used are listed in Table 2. For all test specimens, a W/C of 0.18 was applied. Sand with grain size smaller than 0.6 were used. Natural crushed basalt graded from 1.18 mm to 10.0 mm (max. nominal size) was used as a coarse aggregate. To improve fluidity, a high performance water-reducing agent, Sikament - NN super plasticizer (SP) was added. to investigate the effect of steel fiber volume fraction and aspect ratio on the mechanical properties, steel fibers with a length of 30 mm and a diameter of 1.0 mm and steel fibers with a length of 50 mm and a diameter of 1.0 mm were considered in three different volume fractions (0%,1%, 2% and 3),with aspect ratios (50 and 30) leading to seven series of test specimens. The properties of steel fiber are presented in Table 3. The test specimens were cured at clean tab water for 28 days.

**Table 1 Mix proportions**

| Material | | mix | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Cementinuos material | Cement, c | 720 | 720 | 720 | 720 | 720 | 720 | 720 |
| | Silica fume, s | 215 | 215 | 215 | 215 | 215 | 215 | 215 |
| Coarse aggregates | Basalt 1.18 - 2.36 mm | 190 | 187 | 187 | 183 | 183 | 179 | 179 |
| | Basalt 2.36 – 5 mm | 477 | 467 | 467 | 457 | 457 | 448 | 448 |
| | Basalt 5 – 10 mm | 286 | 281 | 281 | 274 | 274 | 269 | 269 |
| Fine aggregates | Sand | 408 | 400 | 400 | 392 | 392 | 384 | 384 |
| Steel fibers | volume fraction(Vf) | 0 | 1 % | 1 % | 2 % | 2 % | 3 % | 3 % |
| | aspect ratio (l/d) | 0 | 30 | 50 | 50 | 30 | 50 | 30 |
| Water, w | | 129.6 | 129.6 | 129.6 | 129.6 | 129.6 | 129.6 | 129.6 |
| Super plasticizer | | 32.4 | 32.4 | 32.4 | 32.4 | 32.4 | 32.4 | 32.4 |
| w/c | | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 |

**Table 2 Mechanical properties of cement**

| Property | Results | E.S.S limits |
|---|---|---|
| Consistency of standard cement paste | Water content as percentage by weight of cement = 28 % | 26% - 33 % |
| Setting time | Initial = 1 hrs. , 30 min. Final = 4 hrs. , 30 min. | Min. 45 min. Max. 10 hrs. |
| Compressive strength | 3 days = 250 kg/cm$^2$ 7 days = 340 kg/cm$^2$ | Min. 180 kg/cm$^2$ Min. 270 kg/cm$^2$ |
| Fineness of cement | 3300 cm$^2$/gm | Min. 2750 cm$^2$/gm |

**Table 3 Properties of steel fiber**

| Property | Value |
|---|---|
| Specific gravity | 7.8 |
| Tensile Strength | 800 - 1500 Mpa |
| Crimped height | 2-3 mm |

### *B. Test setup and procedure*

***1- Compression test***

The compression test was carried – out on cube specimens (100 * 100 * 100 mm) and cylinders with (100 mm diameter and 200 mm height) after 28 days curing. The preparation of the cylinders for testing was somewhat more involved than that normally used for cylinder testing. The largest difference is that the end planeness of the cylinders was ensured through the use of an end grinder. Compression tests were completed primarily according to the ASTM C39 standard test method for cylinders and the ASTM C109 standard test method for cubes. A slight modification to ASTM C 39 and ASTM C109 was made to make the testing of UHPFRC more practical, namely the increase of the load rate applied to the specimen. The current standard sets the load rate at 35 ± 7 psi per second which would dictate that a specimen of UHPC could take up to 15 minutes to break. This lengthy time period would be unacceptable for the time required to break specimens for production use.

***2- Modulus of Elasticity and Poisson's Ratio***

The modulus of elasticity and Poisson's ratio were conducted on 100 mm diameter and 200 mm height

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cylindrical specimens. Specimen ends were prepared as described for compression testing. The testing process followed ASTM C 469, except the load rate was increased to 150 psi per second as mentioned for the compression testing. In this test, electrical strain gauge was located on the face of cylinder specimens in order to measure transverse and vertical displacements. The specimens were completely unloaded at approximately the same rate and the gauges zeroed. This process occurred three times for each specimen, following the ASTM procedure. The initial loading was used to seat the gauges. Data from the second and third loading was averaged and reported as the results for the specimen. Strain for each 0.50 Mpa stress was recorded and were used to calculate the modulus of elasticity. Calculate of elasticity and Poisson's ratio according to ASTM C 469, equations 1, 2.

$E = (S_2-S_1)/(\varepsilon_2-0.000050)$ . ..........................Equation 1

Where:

E = chord modulus of elasticity

$S_2$ =stress corresponding to 40% of the ultimate load of the concrete

$S_1$=stress corresponding to a longitudinal strain of $\varepsilon_1$ at 50 millionths

$\varepsilon_2$=longitudinal strain produced by $S_2$

**Poisson's ratio, to the nearest 0.01, as follows:**

$\mu = (\varepsilon_{t2} - \varepsilon_{t1})/(\varepsilon_2 - 0.000050)$ ) .............. Equation 2

Where:

μ = Poisson's ratio,

$\varepsilon_{t2}$ = transverse strain at mid height of the specimen produced by stress $S_2$, and

$\varepsilon_{t1}$ = transverse strain at mid height of the specimen produced by stress $S_1$.

***3- Flexure strength***

Testing was conducted on 100 x 100 x 500 mm prism specimens. The specimens were demoulded after 24 hours of casting and were transferred to curing tank where in they were allowed to cure for 28 days. ASTM C 1018 (Using a Beam with Third Point Loading) was used to determine the flexural strength. This test consists of loading a small prism at the third points, to create a constant moment region, and recording the load and deflection so the data can be analyzed to give the flexural cracking stress, flexural strength of the fiber reinforced concrete. This configuration loaded the specimens at the third points of the span and created a simple support condition as outlined in ASTM C 78 where the specification for the loading apparatus is given. The deflection measuring was secured to the prism at the neutral axis of the prism, directly above the support points. In each category three beams were tested and their average value is reported. The flexural strength was calculated as follows**:**

$\mathbf{F_{tb}} = \frac{P.L}{b.d^2}$ (M pa)................................. Equation 3

Where:

P = Failure load;

L = Centre to centre distance between the support = 400 mm;

b = Average specimen width = 100 mm;

d = Average specimen depth = 100 mm.

***4- Tension testing (Splitting test)***

Splitting or indirect tensile test was carried out on cylindrical specimens of 100 mm diameter and 200 mm height according to ASTM C 496 after 28 days curing. ASTM C496 indicates that the maximum tensile stress can be calculated based on Equation 4 In this equation, P is the load applied to the cylinder, L and D are the length and diameter, and $F_\theta$ is the tensile stress.

$\mathbf{F_\theta = 2P/\pi LD}$ ……..........…..........................….. Equation 4

## III. EXPERIMENTAL RESULTS

***A. compressive behavior***

Table 4 summarizes the compressive strength test results for various steel fiber (volume fraction and aspect ratio) and age. results showed that compressive strength increase from 4.10% for (UHPFRC) with steel fiber volume fraction equals 1% comparing with (UHPC) without steel fibers. to 18.0 % for (UHPFRC) with steel fiber volume fraction equals 3% comparing with (UHPC) without steel fibers. Figure (1 and 2) represents the effect of steel fiber content (volume fraction and aspect ratio) on compressive strength at age 28 days. From results aspect ratio of steel fiber at the seam value of volume fraction appears a slight improvement in compressive strength with range of 2%. Compression test on high strength concrete would result in a very brittle failure. The UHPC that is reinforced with steel fibers didn't exhibit explosive failures during compression tests. compressive strength of UHPFRC can be measured, relatively accurately, through cubes or cylinders. The cubes tended to exhibit slightly higher strengths on the order of 10% than cylinders for concrete with steel fibers and 15% for concrete without steel fibers. Figure 3 Represent Compressive strength Results for age 7 and 28 days at different steel volume fraction and aspect ratio, The results show that compressive strength at test age 7 days roughly equal 80 % from the compressive strength at test age 28 days. Table **5** and Figure **4** is a graphical representation of the compressive strain at peak stress at age of 28 days for cylinder specimens with steel fiber (0, 1%, 2%, and 3%) and aspect ratio (30, 50). Test results showed that the compressive concrete strain is directly proportional to amount of steel fibers. It can be seen that all the specimens exhibited linear behavior from initial loading up to the occurrence of the first crack. After the formation of the cracks, all specimens showed non-linear behavior. Figure **5** showed the effect of steel fiber volume fraction and aspect ratio on compressive strain at peak stress. The results showed that long fibers had a better post peak to that of small fibers. Specimens without fiber fracture suddenly in brittle fashion when they reach to ultimate stress at strain

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equal 0.0025 while specimens with fiber fracture with ductile manner at strain equal 0.005 at peak stress.

**Table 4 Compressive strength results**

| mix | specimens shape | compressive strength | |
|---|---|---|---|
| | | test age (days) | Mean strength (Mpa) |
| 1 | cube | 7 | 120 |
| | cube | 28 | 143 |
| | cylinder | 7 | 103 |
| | cylinder | 28 | 124 |
| 2 | cube | 7 | 126 |
| | cube | 28 | 151 |
| | cylinder | 7 | 114 |
| | cylinder | 28 | 137 |
| 3 | cube | 7 | 130 |
| | cube | 28 | 154 |
| | cylinder | 7 | 128 |
| | cylinder | 28 | 141 |
| 4 | cube | 7 | 135 |
| | cube | 28 | 163 |
| | cylinder | 7 | 133 |
| | cylinder | 28 | 147 |
| 5 | cube | 7 | 134 |
| | cube | 28 | 160 |
| | cylinder | 7 | 121 |
| | cylinder | 28 | 145 |
| 6 | cube | 7 | 141 |
| | cube | 28 | 169 |
| | cylinder | 7 | 128 |
| | cylinder | 28 | 154 |
| 7 | cube | 7 | 139 |
| | cube | 28 | 166 |
| | cylinder | 7 | 127 |
| | cylinder | 28 | 151 |

**Table 5 Compressive strain at peak stress**

| mix | Compressive stress (Mpa) | Concrete strain at peak stress $*10^{-3}$ |
|---|---|---|
| 1 | 124 | 2.5 |
| 2 | 137 | 3.5 |
| 3 | 141 | 3.75 |
| 4 | 147 | 4.50 |
| 5 | 145 | 4.25 |
| 6 | 154 | 5.0 |
| 7 | 151 | 4.75 |

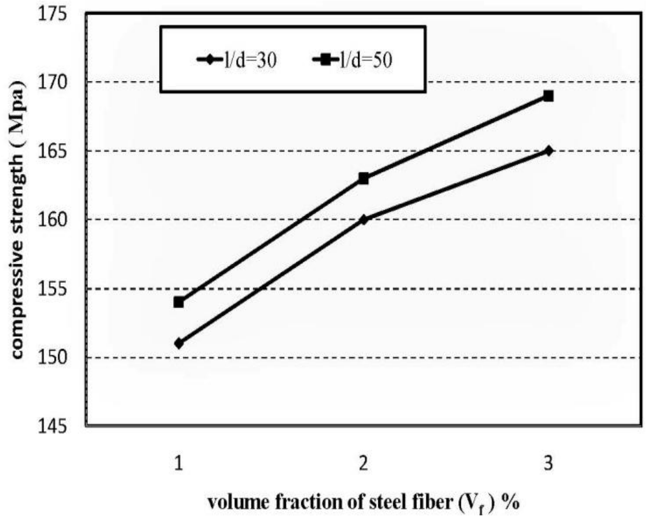


**Fig 1: Mean Compressive strength at different steel ratio and aspect ratio for cub specimens.**

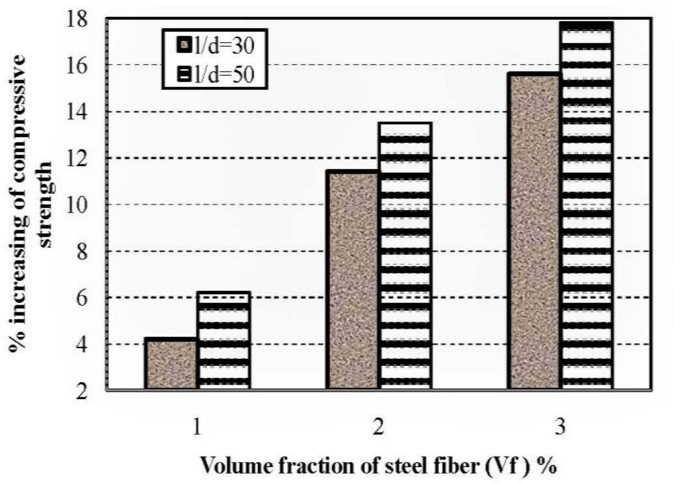


**Fig 2 : % increasing of Compressive strength at different steel volume fraction and aspect ratio**

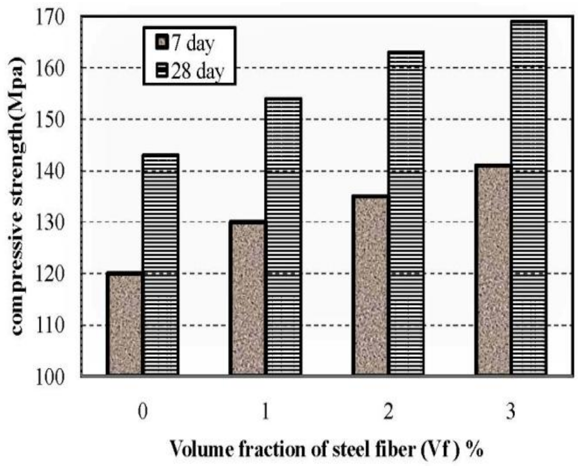


**Fig 3: Compressive strength at age 7 and 28 days**

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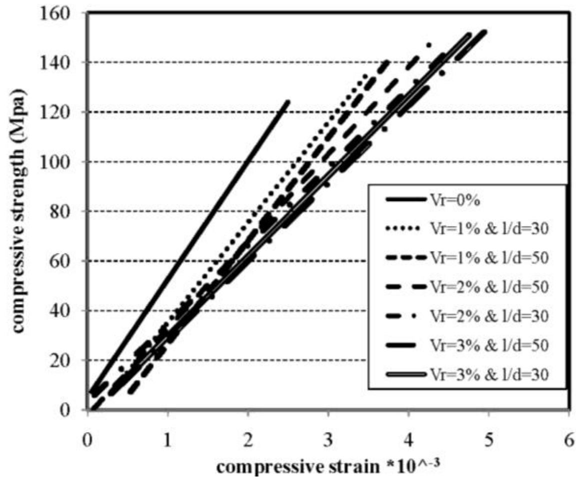


**Fig 4: compressive stress - strain curve.**

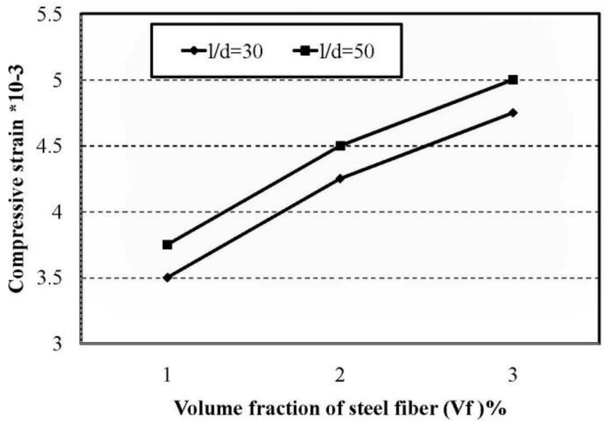


**Fig 5: Compressive strain at different steel fiber ratio and aspect ratio**

### *B. Modulus of Elasticity and Poisson's Ratio*

Table 6 summarizes the mean modulus of elasticity and Poisson's Ratio based on steel fiber volume fraction and aspect ratio. From results It can be seen that steel fiber increase modulus of elasticity up to 13% comparing with concrete without steel fiber. Steel fiber had a little effect on Poisson's ratio results can be neglected. Figure 6 and 7 show the effect of steel fiber on results of modulus of elasticity. The linearity of the compressive stress-strain response of UHPC was investigated through the stress - strain results that were described in the previous section. The results showed that the stress strain curve appear to be linear up to (70% -80%) of compressive strength. Stress - strain curve for UHPC without steel fiber didn't have descending branch this because of brittleness of material. while in UHPFRC , descending branch of stress - strain curve appear clearly . The slope of the descending branch depends on - fiber content, - fiber geometry (length, diameter).

**Table 6 Mean modulus of elasticity and Poisson's Ratio**

| mix | Compressive strength (Mpa) | Mean modulus of elasticity (Gpa) | Mean Poisson's Ratio |
|---|---|---|---|
| 1 | 124 | 45.2 | 0.198 |
| 2 | 137 | 47.90 | 0.199 |
| 3 | 141 | 48.8 | 0.197 |
| 4 | 147 | 49.7 | 0.195 |
| 5 | 145 | 49.0 | 0.20 |
| 6 | 154 | 51.0 | 0.21 |
| 7 | 151 | 50.1 | 0.20 |

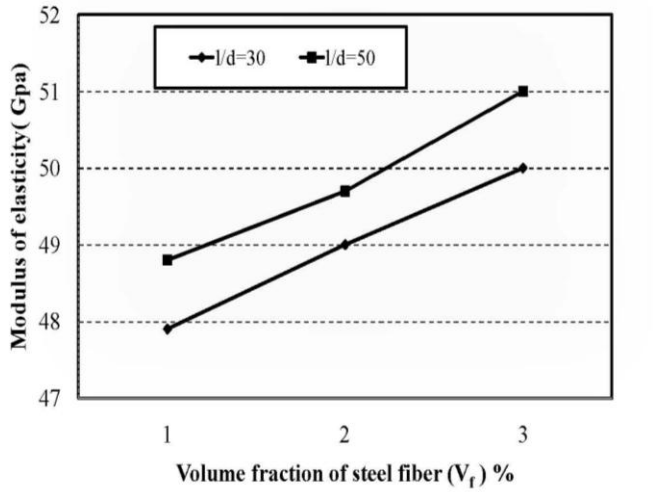


**Fig 6: Steel fiber effect on modulus of elasticity**

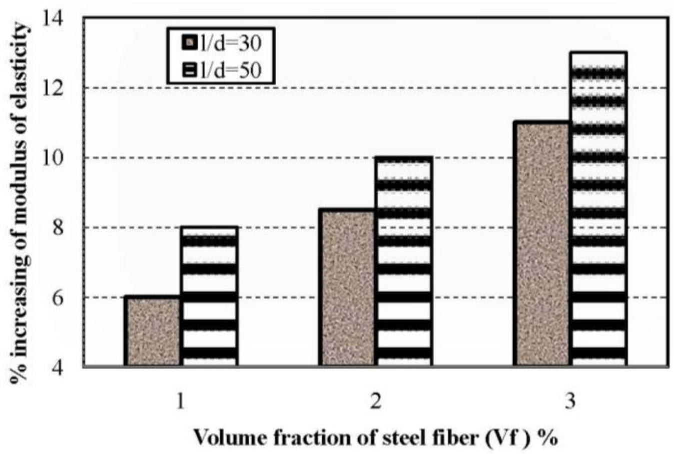


**Fig 7: % increasing of modulus of elasticity Results at different steel volume fraction and aspect ratio.**

### *C. Flexural Strength*

**Table 7** lists the results of the flexural testing for different steel fibers (volume fraction and aspect ratio). The first-crack flexural stress is used as an indicator of the maximum tensile stress for UHPC. ASTM C 78 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) presents the equation as discussed previous. From table **7** It should be noted that, the specimen without steel fibers seem to have a larger first-crack stress than the specimen cast with steel fibers. This can be explained looking at the nature of the material from a homogeneous standpoint. The fibers are geometrically the largest material in the mix and create irregularities in the mix along the interface of the fibers and

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the paste. When looking at the small scale, fibers create a non-homogeneous mixture and cause disruptions in the matrix and allow micro cracking to propagate more readily through the specimen than through the homogenous matrix without fibers. Hence the lower first-cracking stress in UHPC with fibers. However, the difference in first-cracking stress is very small and, as Mindess et al. [5] points out, the purpose of the fibers is to bridge the crack and provide post-crack ductility. From results of flexure test, it can be seen that steel fiber had large effect on flexure strength, flexure strength increase with range up to 40% comparing with concrete without steel fiber, although final deflection of tested prism affected Cleary with steel content. Figure 8 show the effect of steel fiber on flexure strength and Figure 9 show the effect of steel fiber on maximum deflection of tested prism.

**Table (7) (Cracking and maximum) load, deflection and flexural strength**

| mix | cracking conditions | | | Max. conditions | | |
|---|---|---|---|---|---|---|
| | load KN | flexural strength Mpa | def. mm | load KN | flexural strength Mpa | def. mm |
| 1 | 35 | 14 | 0.90 | 40 | 16 | 1.5 |
| 2 | 32 | 12.8 | 3.0 | 42 | 16.8 | 4.8 |
| 3 | 30 | 12 | 3.1 | 46 | 18.4 | 6.0 |
| 4 | 33 | 13.2 | 3.35 | 50 | 20 | 10.0 |
| 5 | 32 | 12.8 | 3.2 | 48 | 19.2 | 7.7 |
| 6 | 34 | 13.6 | 3.4 | 56 | 22.4 | 14.2 |
| 7 | 33.5 | 13.4 | 3.25 | 54 | 21.6 | 12.5 |

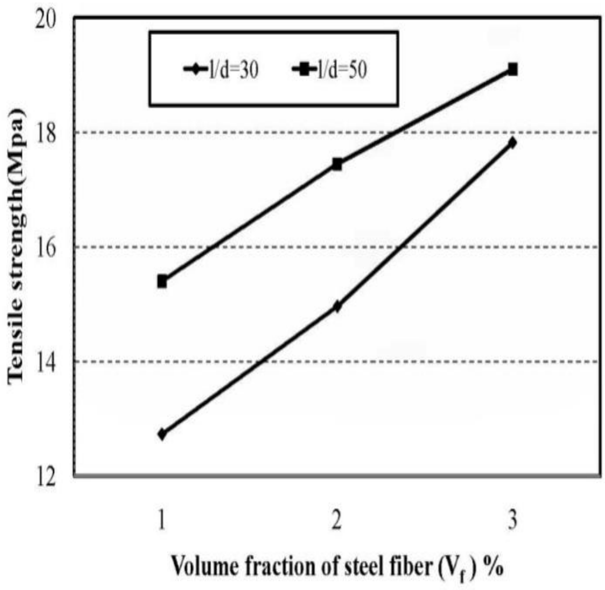


**Fig 8 : Effect of steel fiber on flexure strength**

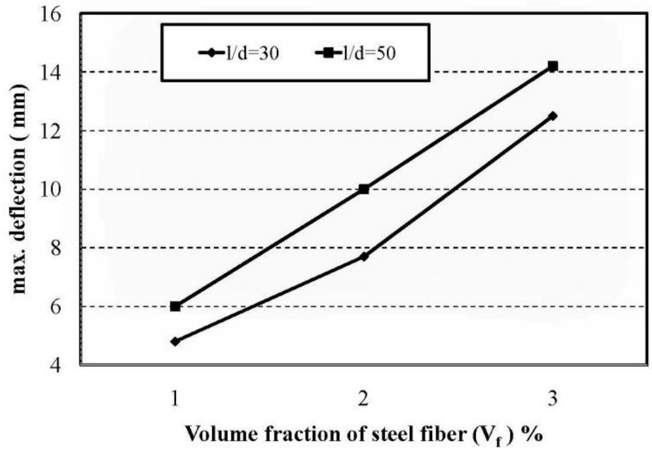


**Fig 9: Effect of steel fiber on maximum deflection**

### *D. indirect tensile test*

Splitting or indirect tensile test were conducted to determine the tensile properties of UHPC. A total of 21 cylindrical specimens with diameter 100 mm and height 200 mm were cast with different steel fibers (volume fraction and aspect ratio), Table **8** to see the effect that fibers had on the tensile strength. From results of splitting test, it can be seen that steel fiber had large effect on tensile strength, tensile strength increase with range up to 55% comparing with concrete without steel fiber. Figure 10,11 show the effect of steel fiber on tensile strength. Failure mode of UHPC without steel fiber is a brittle failure, while failure mode of UHPFRC with steel fiber combined with large deflection and ductile failure.

**Table 8 Tensile strength results (splitting test).**

| mix | Mean load (Kn) | Mean Tensile strength (Mpa) |
|---|---|---|
| 1 | 360 | 11.5 |
| 2 | 400 | 12.73 |
| 3 | 484 | 15.4 |
| 4 | 548 | 17.45 |
| 5 | 490 | 15.59 |
| 6 | 600 | 19.10 |
| 7 | 560 | 17.82 |

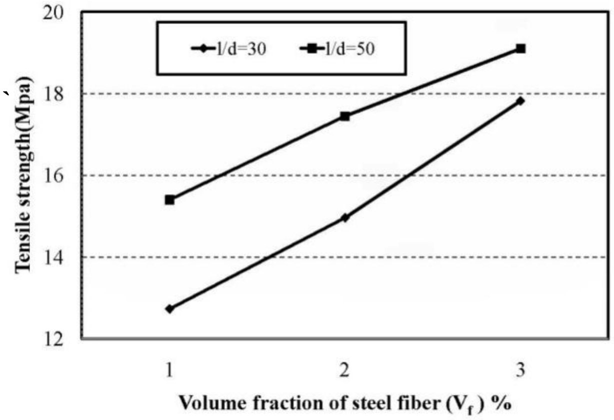


**Fig 10: the effect of steel fiber on tensile strength**

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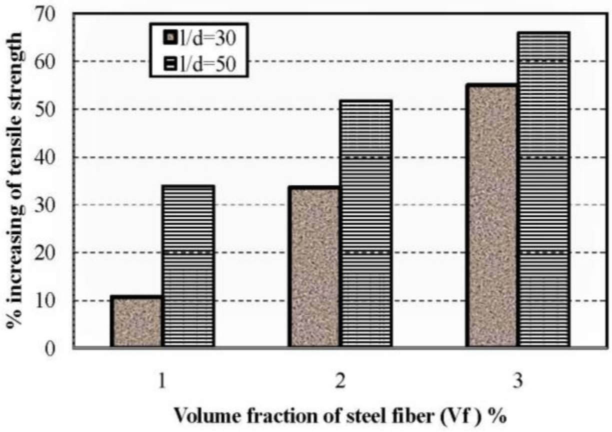


**Fig 11: % increasing of tensile strength Results at different steel volume fraction and aspect ratio.**

## IV. CONCLUSIONS

Results of this research show that it is possible to produce UHPFRC using available local materials that if they are carefully selected. Such concretes can be produced with ordinary Portland cement, silica fume, steel fibers, super plasticizer, fine sand and basalt with ratio as discussed before. From the experimental study and analytical analysis the following conclusions can be drawn:

1. It is observed that compressive strength, modulus of elasticity, splitting tensile strength and flexural strength are on higher side for 3% steel fibers volume fraction as compared to that produced from 0%, 1% and 2% fibers volume fraction.
2. All the strength properties are observed to be on higher side for aspect ratio of 50 as compared to those for aspect ratio 30.
3. It is observed that compressive strength increases from 4.10% for (UHPFRC) with steel fiber volume fraction equals 1% comparing with (UHPC) without steel fibers to 18.0 % for (UHPFRC) with steel fiber volume fraction equals 3% comparing with (UHPC) without steel fibers.
4. It is observed that modulus of elasticity increases from 6.0% for (UHPFRC) with steel fiber volume fraction equals 1% comparing with (UHPC) without steel fibers to 13.0 % for (UHPFRC) with steel fiber volume fraction equals 3% comparing with (UHPC) without steel fibers.
5. It is observed that Poisson’s Ratio had a little effect with steel fiber and can be used equal 0.20 for UHPFRC
6. It is observed that flexural strength increases from 15% for (UHPFRC) with steel fiber volume fraction equals 1% comparing with (UHPC) without steel fibers to 40.0 % for (UHPFRC) with steel fiber volume fraction equals 3% comparing with (UHPC) without steel fibers.
7. It is observed that splitting tensile strength increases from 34% for (UHPFRC) with steel fiber volume fraction equals 1% comparing with (UHPC) without steel fibers to 67.0 % for (UHPFRC) with steel fiber volume fraction equals 3% comparing with (UHPC) without steel fibers..

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