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Influence of hybrid fibers on the mechanical properties of ultra-high-performance concrete incorporating metakaolin and silica fume.

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الملخص العربي :

عيب إنتاج الخرسانة فائقة الاداء هو استخدام كمية كبيرة من الاسمنت، مما يولد العديد من المشاكل البيئية. في هذا البحث، تم تقليل محتوى الإسمنت إلى الحد الأدنى بحيث تقلل الخرسانة فائقة الاداء من التأثير البيئي الناتج أثناء إنتاج الاسمنت وتحقق الاستدامة من خلال دمج محتوى الميتا كولين. بالإضافة إلى ذلك، تمت دراسة تأثير كميات متعددة من ألياف البولي بروبلين، وكذلك ألياف الصلب، من أجل تحديد الكمية المثالية للألياف الهجينة ولتقييم الخصائص الميكانيكية والديناميكية للخرسانة فائقة الاداء. كانت المتغيرات التي تمت دراستها هي الجزء الحجمي للألياف، بمعنى. الياف الصلب (0٪، 2.25٪، 1.5٪، 0.75٪ و3٪) والياف البولي بروبلين (3٪، 0.75٪، 1.5٪، 0.25٪ و0٪) ونسبة مئوية ثابتة من دخان السليكا (25٪) والميتاكولين (10٪). أظهرت النتائج أن مقاومة الانضغاط للمركب كانت 155 ميجا باسكال بالرغم من انخفاض استهلاك الأسمنت بواقع 700 كجم / م 3 مع 75٪ ألياف فولاذية و25٪ ألياف بولي بروبلين. بالنسبة للتركيبة المكونة من 75٪ ألياف فولاذية و25٪ ألياف بولي بروبلين، زادت مقاومة الانحناء بنسبة 8٪ مقارنة بالمخلوط المحتوي على ألياف فولاذية 100٪، مما يشير إلى فوائد التهجين. أما معامل المرونة فقد زاد بنسبة 2٪ عن مزيج الصلب الأحادي. وفي اختبار الحريق، أظهرت المخاليط المحتوية على مادة البولي بروبلين تشتت أقل بسبب قابليتها للذوبان وانخفاض ضغط البخار الداخلي. علاوة على ذلك، أظهرت النتائج أن إضافة الألياف الهجينة لا تساعد فقط في بناء واجهات أقوى في الخرسانة فائقة الاداء ولكن أيضًا تغير نمط الفشل.

ABSTRACT:

A demerit of UHPC production is the use of a large amount of cement, which generates many environmental problems. In this paper, the cement content was minimized so that the UHPC concrete minimizes the environmental impact generated during cement production and achieves sustainability by incorporating a metakaolin (MK) content. In addition, the influence of several quantities of polypropylene fibers (PP. F), as well as steel fibers (St. F), was studied in order to determine the ideal amount of hybrid fibers and to evaluate the mechanical and dynamic properties of UHPC. The variables studied were the volume fraction of fibers, viz. PP. F (0%, 2.25%, 1.5%, 0.75% and 3%) and St. F (3%, 0.75%, 1.5%, 0.25% and 0%) and a fixed percentage of silica fume (SF) (25%) and MK (10%). The results showed that the compressive strength of the composite was 155 MPa despite the low cement consumption of

700 kg/m^3 with 75% steel fibers and 25% polypropylene fibers. For the composition consisting of 75% steel fibers and 25% polypropylene fibers, the flexural strength increased by 8% compared to the mixture containing 100% steel fibers, indicating the benefits of hybridization. as the modulus of elasticity increased by 2% more than mixed mono steel. And in a fire test, mixtures containing polypropylene showed lower dispersion due to their solubility and lower internal vapor pressure. Furthermore, the results show that adding the hybrid fibers not only helps in building stronger interfaces in UHPC but also changes the failure pattern.

Keywords: UHPC matrix, hybrid fibers, Mechanical strengths, modulus of elasticity, MK.

1. Introduction

Ultra-high-performance concrete (UHPC) is a cementitious compound having a compressive strength of over 120 MPa, as well as fantastic durability, toughness, and tensile ductility [1-3]. Cement consumption is increasing to fulfil the increased demand for UHPC in civil infrastructure, resulting in large greenhouse gas emissions and serious environmental effects [4]. On the other hand, during the manufacturing process of UHPC, well-chosen raw materials and complex quenching processes consume a lot of energy, resulting in a significant rise in industrial production cost [5]. As a result, a lot of effort has been put into optimizing the configuration in order to keep making UHPCs at lower cost and power [6].

Fibers are included in UHPC as no less important components with the primary objective of overcoming their brittle character and increasing their tensile strength [7]. Fiberless UHPC has a brittle tensile strength between 7 and 10 MPa, whereas fiber-reinforced UHPC has a higher tensile strength between 7 and 15 MPa and ductile behavior in the stress-strain scheme in the descending region after crushing [8]. Due to their modulus and high strength, St. F fibers are the most common among the many types of fibers employed, which helps reduce fiber breaking in areas with UHPC cracking and gives excellent crack bridging capabilities [9]. When compared with non-fibrous UHPC, the results showed that St. F increases the maximum compressive strength via about 12%, although there is no significant change in the maximum compressive strength between 2 and 4% in terms of fiber volume. St. F is a common large fiber that can fill large cracks and reduce their expansion over a wide range; but, the inhibitory effect of SF on early-appearing microcracks is limited [10, 11].

When mixed with steel fiber to produce a hybrid fiber system, polypropylene fiber (PP. F), a common type of micro-fiber, has been proven to successfully improve the overall qualities of the cementitious material. For example, Yu et al. found that UHPC with St. F (2% by volume) and PP. F (0.4% by volume) has a maximum flexural strength of approximately 25 MPa, which is much higher than St. F alone (approximately 19 MPa) [12]. PPF can also be chemically inert in the alkaline environment of concrete because it is non-corrosive and thermally stable [13]. Moreover, PP F has a hydrophobic surface, which means that it does not impede the water reaction of concrete [14]. It was also confirmed that adding PP. F to regular reinforced concrete improved the bonding behavior of St. F [15]. As a result, a combination of St. F-PP. F in concrete might significantly improve benny conditions by minimizing the occurrence and reproduction of concrete fractures by leveraging the material features of the two fibers [6]. PP. F, which connects the micro-cracks in the ITZ for UHPC with aggregates [12], [16] it can also be used to link the interfacial transition zone (ITZ) between the aggregate and the matrix. In reality, the UHPC's compression response is the foundation for successful structural analysis and design. Several studies on the modulus of elasticity as well as the compressive strength of UHPC have been conducted so far, considering a variety of influencing parameters such as sample size, pretreatment, steel fibers, casting direction, loading speed, etc., [17, 18].

The microstructure and properties of the cement's hydration products alter when exposed to high temperatures, which changes the substrate's macroscopic properties and impacts the general behavior of hardened concrete [19]. It may be difficult to release vapor pressure under fire and high temperatures due to the limited porosity of the UHPC. As a result, UHPC constructions perhaps more sensitive to fire and high-temperatures, resulting in harm [20]. Polypropylene fibers PP. F, on the other hand, can avoid chipped damage [21-23]. According to the research, adding 0.6% PP. F (volume ratio) to UHPC improves fire resistance and prevents chipping [24]. This is due to the PP. F creating an exhaust steam path after melting at high temperatures, allowing the pressure to be released. The mechanical characteristics of UHPC have also been damaged due to drying of hydrated calcium silicate colloid (C-S-H) and damage induced by thermal expansion and chemical decomposition and of UHPC materials [20]. The compressive strength of UHP increased with rising temperature up to 300 °C, according to Tai et al. [25]. However, after the temperature above 300 °C, the compressive strength began to decrease. The mechanical decomposition of UHPC occurs at high temperatures due to the poor internal microstructure [25]. The modulus of elasticity, an essential factor in the design as well as studying concrete structures, could influence deformation of concrete during the elastic phase and at the start of cracking. The modulus of elasticity of (UHPC) with high compressive strength and great toughness is usually in the range of 40-60 GPa, which is 20-70% higher than that of concrete.

From the previously published results, it was found that there has not been enough research on hybrid fiber-reinforced UHPC. Hence, the aim of this research is to study the influence of adding two types of fibers to concrete mixtures and designing these mixtures with the optimum amount of steel fibers and polypropylene on the resistance of UHPC to failure, and an attempt has been made to study the influence of different proportions of steel fiber and polypropylene fibers for strength of UHPC. The influence of mono polypropylene fiber and mono steel fiber in UHPC is also investigated and reported.

2. Experimental methods
2.1. Materials

Through the experimental study, Portland cement (PC) type CEM I 52.5N in according to BS EN 197-1/2011 [26] has been employed as the main binder material. MK and SF were used as partial addition of cement at rates of 10% and 25% for by the mass of cement. Table 1 illustrates chemical properties of all cementitious materials used. The total content of the cementitious materials was 945 kg/m^3. Silica fume has an average diameter of 8 µm, a SiO_2 content of 97.8%, a specific gravity of 2.2, and a specific surface area of 21,000 m^2/kg. MK, had a specific gravity of 2.57, respectively, and their Blaine areas were 19000 m^2/kg, and a specific surface area of 4200 m^2/kg. The silica fume used was a high silicon material that met the initial criteria of ASTM C1240-14 [27]. In concrete compositions, Quartz powder (QP) has been used with very small particles from 0.3mm to 1.2mm, specific gravity 2.61.

To enhance packing density in concrete, the water/binder ratio (w/b) was fixed at 0.18. Natural sand was employed as the fine aggregate in this investigation, and it was evaluated according to ASTM C33/C33-18 [28]. The natural sand utilized has a particle size range of 0.125 to 0.6 mm, a specific gravity of 2.65, a volume density of 1.79 t/m^3, and a 0.9 percent water absorption. Moreover, to examine the effect of hybrid fibers on mechanical and dynamic properties, two different types of fibers were considered in this study, namely St. F and PP. F, as shown in Fig.1. Detailed properties of fibers are listed in Table 2. To increase the flowability of UHPC, an abased high-range water reducer with a dose of 2.5% by mass of cementitious materials was utilized.

Table 1. Chemical properties of the cementitious materials used.

Chemical component	PC	MK	QS	SF
CaO	63.02	0.78	0.02	0.27
SiO_2	20.05	53.3	98.85	97.80
Al_2O_3	4.26	30	0.08	0.34
Fe_2O_3	2.82	4.33	0.05	0.17
SO_3	3.15	-	3.14	-
Na_2o	0.38	0.26	-	0.23
K_2O	1.24	0.62	-	0.15
MgO	3.80	0.16	-	0.21
P_2O_5	-	-	0.04	-
Mno_2	-	-	-	-
Tio_2	-	-	-	-
L.O.I. (%)	2.3	0.98	-	2.0

Table 2. properties of the fibers.

Material	Length (mm)	Diameter (mm)	Density (Kg/m^3)	Tensile Strength (MPa)	Elastic Modulus (GPa)
Steel	12.5	1	7850	750	203
Polypropylene	6	0.035	910	400	3.5

(a)

(b)

Fig 1. Hybrid fibers used in this study (a) PP. F and (b) St. F.

2.2. Mixture proportions

Table 3. describes the concrete mix design program used in this study. The control mixture (M_0) does not contain steel fibers or polypropylene fibers for comparison. Six experimental mixtures were made with different proportions of UHPC mixtures. The three parameters of interest were: addition of MK to all mixtures, steel fibers (volume %), and polypropylene fibers (volume %). The superplasticizer concentrations in the cementitious materials were 2.5 percent by weight. The weight ratio of fine aggregate and quartz sand was maintained in all mixtures.

Table 3. Mixing ratio of UHPC (kg/m^3).

Mixture	C	F	K	S and	P	S P (%)	/b	S t.F	] P.F
M$_0$	00	75	0	1 122	75	2 .5	.18	(	**(**
3SF	00	75	0	1 122	75	2 .5	.18	2 34	**(**
0.75SF0 .25PP	00	75	0	1 122	75	2 .5	.18	1 75.5	**(.8**
0.5SF0. 5PP	00	75	0	1 122	75	2 .5	.18	1 17	**1 3.6**
0.25SF0 .75PP	00	75	0	1 122	75	2 .5	.18	5 8.5	**2 0.5**
3PP	00	75	0	1 122	75	2 .5	.18	(	**2 7.3**

PC: Portland Cement, SF: Silica Fume, MK: Metakaolin, SP: superplasticizer, QP: quartz powder, St. F: steel fibers, PP. F: polypropylene fiber, w/b: water/binder ratio.

The proportions of concrete for every group have been mixed via a single shaft forced mixer, as well as the mixing procedure, has been as follows:

(1) Only the PC, MK, SF, and aggregates were placed in the mixing tank and then mixed for 5 min.

(2) Water with a proportion of the superplasticizer was poured in the mixer after mixing for 2 minutes.

(3) The fibers are gradually introduced (steel fiber and polypropylene fiber).

(4) Finally, the remaining water and superplasticizer were poured into the mixer and mixing process has been continued for another 5 min until fresh concrete was produced.

2.3 Sample preparation and treatment

After mixing the concrete, the fresh properties of each mixture were recorded. To determine the mechanical properties and durability of UHPC, suitable molds were used for sample preparation. Before preparing the UHPC mixture, the formwork is properly cleaned, lubricated, and fixed before preparing UHPC mixture to ensure that there are no leaks when pouring concrete. To expel the air voids in the concrete mixture and to ensure compaction, a table vibrator has been used, the mixture is poured into the molds and stays in the molds for 24 hours. at 24°C. After pouring, all samples have been covered with polyethylene sheets for 24 hours overnight, then the molds have been removed and all have been placed in a container of water until testing time.

2.4. Test methods and devices

In Table 4 the tests performed for UHPC are (density, slump flow, compressive strength, modulus of elasticity, tensile strength, and flexural strength) performed as per ASTM listed specifications [29-34. Samples were heated at a specified medium (3°C/min) to an oven temperature meeting the target temperature to test the effects of high temperatures on the mechanical properties of the UHPC. The oven temperature was set for 30 minutes after the highest objective temperature was reached to improve the thermal stability of the entire sample. The furnace was then switched off and the sample was allowed to cool to room temperature by opening the furnace door before the residual force test.

Table 4. Method of testing the properties of concrete**.**

Property	Experimental Method
density	ASTM C138
Slump	ASTM C143
Compressive strength	ASTM C39
Splitting tensile strength	ASTM C496
Flexural strength	ASTM C78

2.6. Modulus of elasticity

Fig. 4 shows the modulus of elasticity measurement for each twenty-eight-day-old concrete mixture. The standard ASTMC 469-75 (1975) [32] was used to estimate the constant elasticity modulus (Ec) in compression. Samples were loaded with pressure (2 kg/cm^2), and then increased to (Y+ 7), where Y represents one third of the maximum compressive strength. About 11.2 kg/cm^2 of additional loading was gradually added. The displacement (Δl) was measured with a scale at each increase in load, and the stress was calculated as /L_0, where L_0 is the distance between the device axes. These steps were used to accomplish 3 loading/unloading cycles. As a measure of concrete's modulus of elasticity, stress-strain curves were plotted using the regression of the latest load cycle. As samples have been loaded every 2 tons, as well as measuring the strain that occurs to the sample, the loading arrived at 40 tons**.**

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Fig. 4. Modulus of elasticity.

3. Results and discussions

3.1. Dry density

Fig 5. Shows the solidification density of UHPC mixtures using hybrid fibers. In general, the density of concrete mixtures decreases as the steel fiber content decreases and the polypropylene fibers increase. This could be explained by the polypropylene fibers lower density compared to that of steel fibers and the density of concrete increases with the increase of steel fibers. It was observed that the lowest density was the control mixture among the studied mixtures. The highest density is found in the 3St.F mixture.

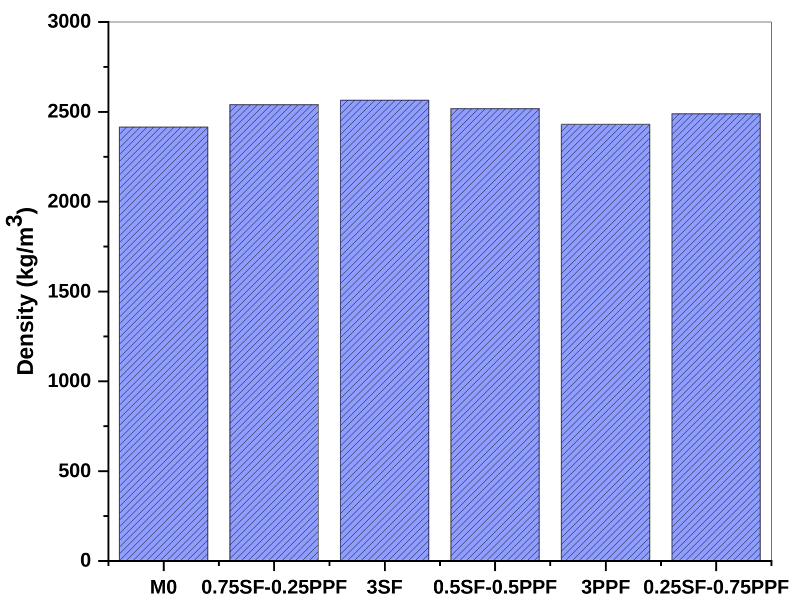


Fig. 5. Density of UHPC hardening mixtures.

3.2. Fresh concrete properties

A slump test has been performed to evaluate effects of St. F and PP. F on UHPC operability in line with ASTM C143 [30]. In this test, a truncated cone (top diameter 100 mm, bottom diameter 200 mm, height 300 mm) was filled with concrete in three layers, each pressed with 25 S, later, the mold was slowly raised, and the value was determined. Table 5 shows that the operability ranges from 230 to 260 mm. Both control mixture as well as other mixtures had fairly acceptable workability. The flow of the control mixture is 260 mm which indicates very good fluidity. For other blends, the workability of each blend was less than M_0 because the incorporation of the fibers, but they also have sufficient fluidity.

Table 5. Fresh concrete properties results.

Mixture	Slump flow (mm)
M_0	260
3SF	250
0.75SF0.25PP	245
0.5SF0.5PP	241
0.25SF0.75PP	236
3PP	230

3.3. Properties of hardened concrete

Production characteristics of hardened concrete such as flexural strength, modulus of elasticity, and compressive strength, within two days and seven days, as shown in Table 6. The data in the table are the averages of three samples.

Table 6. Hardened concrete properties results.

Mix.NO	two-day experimental results			Seven-day experimental results		
	fc (MPa)	fs(MPa)	fr(MPa)	Fc (MPa)	fs (MPa)	fr (MPa)
M_0	80	5.6	0.84	69.3	7.5	1.42
3SF	85	12.7	12.4	102	14.5	21.1
0.75SF0.25PP	89	12.9	12.7	105	15	22.4
0.5SF0.5PP	76.35	11.03	9.15	98	12.69	16.3
0.25SF0.75PP	69.3	10.4	5.2	85	11.4	8.03
3PP	82	8.5	2.3	81	9.1	4.4

Note: fs; splitting strength, fr; flexural strength, fc; compressive strength, Ec; elastic modulus.

3.4. Compressive strength

This test has been performed in line with [ASTM C109, 2008 ASTM C109 / C109M, 2008]. Several mixing experiments were ready for each batch of UHPC 50x 50x50 mm concrete cubes. Table 7 shows the mean values obtained from three samples that were prepared and evaluated. Fig. 6 displays the samples after the compressive strength test. By dividing the highest load across the loaded area, the sample compressive strength in (MPa) is revealed:

$$\sigma = \frac{P}{A} \tag{1}$$

Where:

a = sample cross-sectional area, P = maximum load applied across the cube sample during.

Table 7. Develop compressive strength.

Mix NO	f c−28d	f c−90d	f c−28d /f c-90d
M_0	90	110	0. 82
3SF	135	152	0.88
0.75SF0.25PP	138	155	0.89
0.5SF0.5PP	130	146	0.89
0.25SF0.75PP	120	133	0.90
3PP	93	117	0.79

Note: f c; compressive strength, f c−28d/90d; standard deviation.

(a) (b) (c)

Fig. 6: Test sample failure under pressure: (a) M_0, (b) 3SF and (c) 0.5SF0.5PP.

3.5. Splitting tensile strength

Regarding the splitting resistance of concrete, as shown in Table 8. The test outcomes have been between 12 and 18 MPa, the M_0 mixture had the lowest cleavage resistance 12 MPa and the 0.75SF0.25PP mixture was the highest 18 MPa in 90 days. This suggests that the amount of steel fiber in concrete has a significant impact on its cleavage strength. Fig. 7 depicts brittle failure in the control mixture, while the other mixes retained their original look after reaching the final load with no significant stress or deformation.

Table 8. Splitting tensile strength of UHPC mixture.

Mix	fs-2D	fs-7D	fs-28D	fs-90D
M_0	5.6	7.5	10.6	12
3SF	12.7	14.5	16	17
0.75SF0.25PP	12.9	15	17	18
0.5SF0.5PP	11.03	12.69	14.7	15.7
0.25SF0.75PP	10.4	11.4	13.5	14
3PP	8.5	9.1	12	12.45

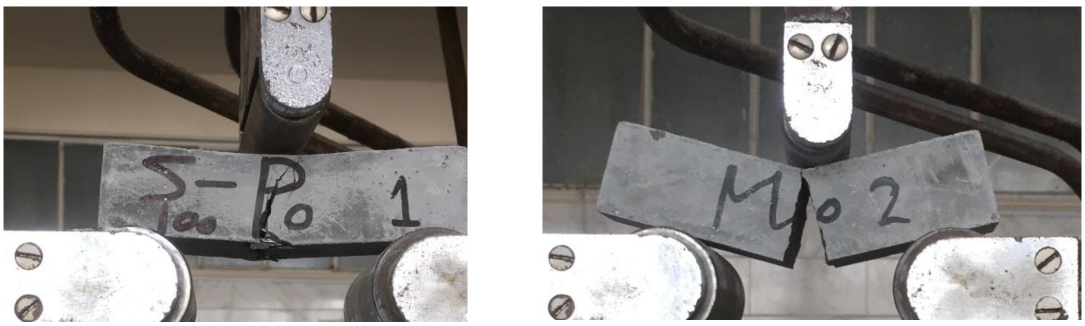
Not: fs; splitting strength.

(a) (b) (c)

Fig .7. Comparison of splitting test results: (a) M_0 samples, (b) 3SF and (c) 0. 5SF0.5PP.

3.6. Flexural strength

The twenty-eight-day bending strength of the concrete mixes was between 5 and 30 MPa, as illustrated in Table 9. The M_0 mixture was lower bending resistance 5 MPa and the 0.75SF0.25PP mixture had the highest 30 MPa. In general, the control mixture clearly showed brittle failure as displayed in Fig. 8-a, while the bending strength of the mixtures containing the hybrid fibers had greater load bearing ability and better bending performance than the M_0 because the steel fibers had the ability to fill the cracks as obvious in Fig. 8b. This indicates that steel fiber content can be a major element in bending concrete resistance.



(a) **(b)**

Fig .8. The experimental specimen (a) 3SF and (b) M_0 failed the flexion test

Table 9. Flexural test preparation.

Mix	fr-2D	fr-7D	fr-28D
M_0	2.84	3.42	5
3SF	14.6	23.4	28
0.75SF0.25PP	15	24.4	30
0.5SF0.5PP	11.15	17.3	19
0.25SF0.75PP	7.2	9.03	12
3PP	3.3	4.4	6

Note: fr, flexural strength.

3.7. Modulus of elasticity of concrete

As shown in Figure 9, the modulus of elasticity of the samples reached by the stress-strain curve according to the American standard ASTM C469 for twenty-eight days ranged between 36 and 43 GPa. Due to the lack of hybrid fibers, the M_0 mixture had the lowest modulus of elasticity 36 GPa, while the 0.75SF0.25PP mixture had a higher modulus of elasticity 43 GPa. However, in the control mixture, it found little variation in the elasticity modulus for the fiber-containing concrete mixtures. It was as well found that polypropylene fibers had little effect on the modulus of elasticity. Especially for the 3PP.F and 0. 25St.F-0. 75PP.F mixture, the modulus of elasticity at 28 days was almost higher than the modulus of the M_0.

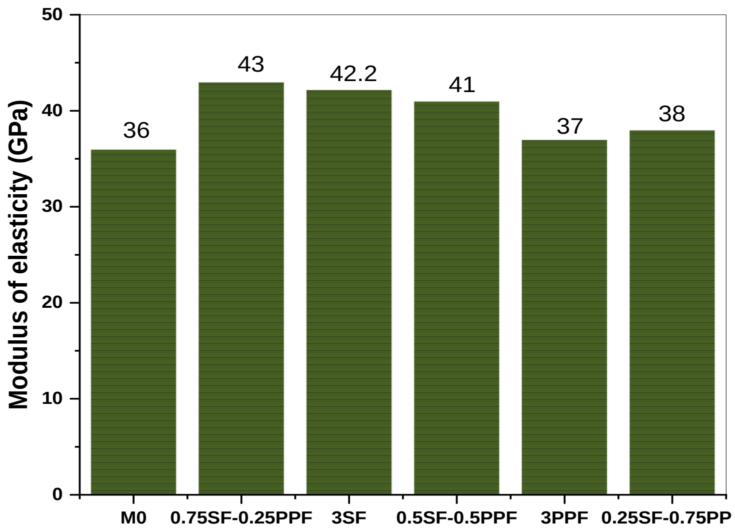


Fig. 9. Modulus of elasticity**.**

3.8. Effect of high temperatures

All compressive strengths of mixtures were examined after exposure to high temperatures in an electric oven to understand the impact of high temperatures on the mechanical quality of UHPC. In general, in the blaze test, the electric oven warming ratio demonstrated powerful effects. In this study, the target temperature (800°C) was reached with a warming average of 20, 15, 10, and 4°C/minute, and the oven temperature was maintained for an extra 30 min. However, as seen in Fig. 11a–d, this resulted in sample fragmentation in all of the aforesaid scenarios. To obtain the goal temperature (200°C), the heating rate was changed to 2°C/minute, and the temperature was sustained for 0.5 hours, as shown in Fig. 11e. There were three types of temperature extremes: 400, 600, and 800 degrees celsius. After the target temperature was reached, the temperature was maintained for half-hour. The oven was then turned off to allow the samples to cool to room temperature naturally. Fig. 10 shows the results of the compressive strength test before and after exposure to temperatures of 200 °C after 28 days of normal treatment. After heating the 0.75SF0.25PP sample to the required temperature for 0.5 hours, cooling naturally in an electric furnace, and leaving for 24 hours, the compressive strength reached 150 MPa.

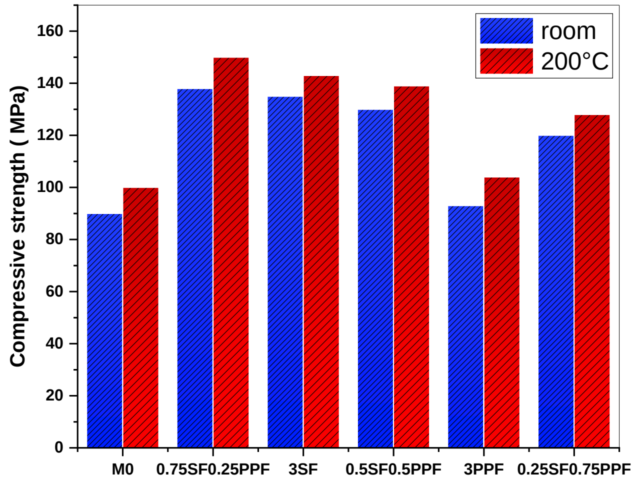


Fig.10. Results of the properties of hardened concrete for 28 days before and after exposure to temperatures of 200 ° C.

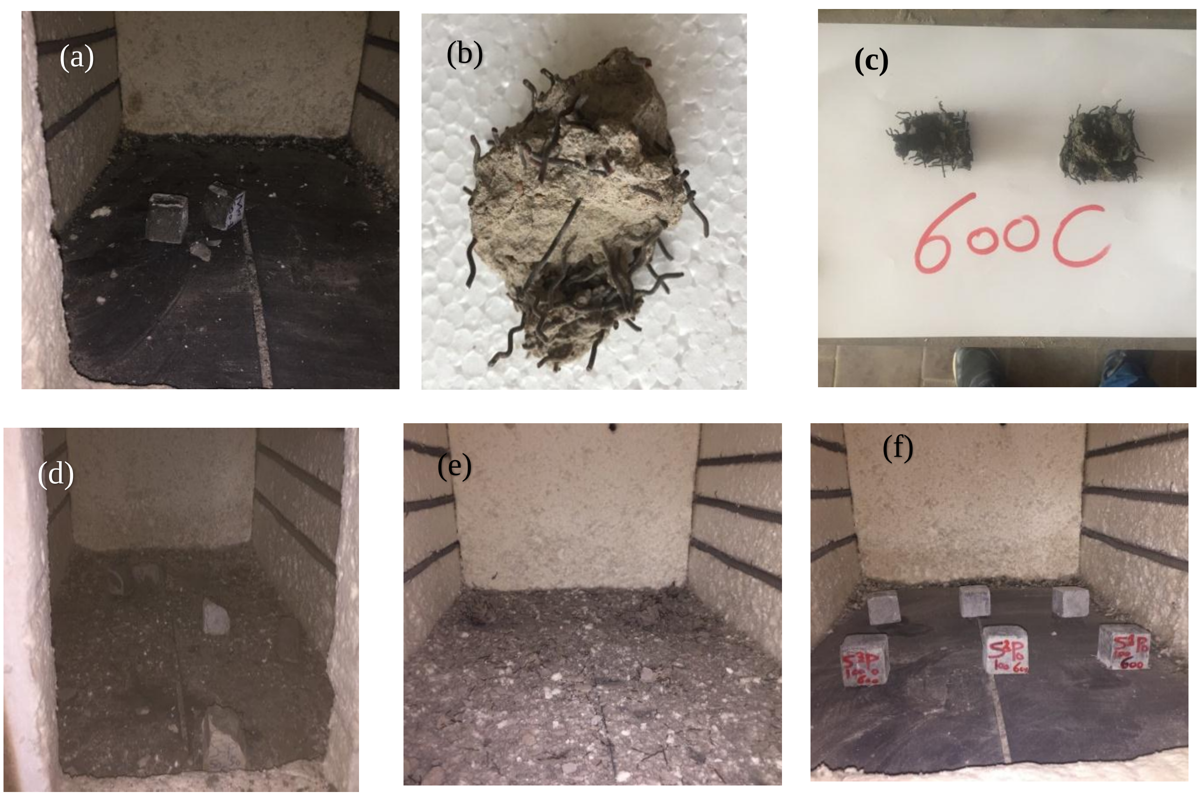


Fig. 11. Samples rupture after high temperature: (a) M_0 at a target temperature of 200°C, (b) 3 St. F at a target temperature of 400°C, (c) 0. 75St.F0.25PP. F at a target temperature of 600°C, (d) 0. 5St.F0. 5PP.F at a target temperature of 800°C, (e) 0.25St. F - 0. 75PP.F at a target temperature of 500°C, and (f) 3PP.F at a target temperature of 200°C**.**

4. Conclusions

In this paper PP. F and St. F were added with different volume contents (0%, 0.25%, 0.75%, 0.5, and 3%). The effect of St. F and PP. F on the mechanical properties (compressive strength, tensile strength, bending strength, fire test, and modulus of elasticity) of UHPC were evaluated. According to the tests, the results can be summarized as follows:

- The workability of UHPC with the addition of PP. F decreased by 1.2%, 1.6%, 2.4%, and 3.5% with the use of PP. F (0.25%, 0.75%, 0.5% and 3%) respectively compared the control mixture. In contrast, UHPC workability was increased by up to 2% in St. F compared to PP.F.

- The study shows that increasing the amount of polypropylene fibers in the mixture reduces the density of the UHPC, which is related to the increased porosity in the sample. However, when the amount of steel fibers increases, the density increases.

- The results indicate the addition of hybrid fibers improve the mechanical properties of UHPC compared to mono fibers. The 0. 75St.F-25PP.F mixture is an ideal mixture compared to other hybrid mixtures, resulting in compressive strength of 155 MPa. The tensile strength, bending strength, increase by 3% with the increase in the proportion of hybrid fibers. This indicates that the hybrid fibers achieve acceptable adhesion as they serve to enhance the sustainability of tensile stresses. Adding fibers to UHPC alters crack patterns, reduces crack appearance, and limits crack expansion in the concrete sample. On the flip side, it helps prevent components from falling upon failure.

- The research also showed that 0. 75St.F0. 25PP.F has a 28-day compressive strength of 138 MPa before temperature exposure to UHPC. The compressive strength of the sample did not decrease significantly after exposure to 200 °C, in fact, it increased by 9%. Due to the drying effect caused by the high temperature, the strength of the sample was slightly increased. As a result, the concrete matrix did not degrade as a result of fire damage. The high temperature of the concrete sample caused the concrete matrix to deteriorate and crack when the fire damage was more than 400, 600°C.

References

[1] Sharma, R., and Bansal, P. P. (2019). Efficacy of supplementary cementitious material and hybrid fiber to develop the ultra-high performance hybrid fiber reinforced concrete. *Advances in concrete construction*, 8(1), 21-31.

[2] Erdogdu, S., Kandil, U., and Nayir, S. (2019). Effects of cement dosage and steel fiber ratio on the mechanical properties of reactive powder concrete. *Advances in concrete construction*, 8(2), 139-144.

[3] Wan, L., Wendner, R., Liang, B., and Cusatis, G. (2016). Analysis of the behavior of ultra high performance concrete at early age. *Cement and Concrete Composites*, 74, 120-135.

[4] Lima, C., Caggiano, A., Faella, C., Martinelli, E., Pepe, M., and Realfonzo, R. (2013). Physical properties and mechanical behaviour of concrete made with recycled aggregates and fly ash. *Construction and Building Materials*, 47, 547-559.

[5] Wille, K., Naaman, A. E., El-Tawil, S., and Parra-Montesinos, G. J. (2012). Ultra-high-performance concrete and fiber reinforced concrete: achieving strength and ductility without heat curing. *Materials and structures*, 45(3), 309-324.

[6] Wang, D., Shi, C., Wu, Z., Xiao, J., Huang, Z., and Fang, Z. (2015). A review on ultra-high-performance concrete: Part II. Hydration, microstructure and properties. *Construction and Building Materials*, 96, 368-377.

[7] El-Dieb, A. S. (2009). Mechanical, durability and microstructural characteristics of ultra-high-strength self-compacting concrete incorporating steel fibers. *Materials and Design*, 30(10), 4286-4292.

[8] Le Hoang, A., and Fehling, E. (2017). Influence of steel fiber content and aspect ratio on the uniaxial tensile and compressive behavior of ultra-high-performance concrete. *Construction and Building Materials*, 153, 790-806.

[9] Wu, C., Li, J., and Su, Y. D. (2018). Development of ultra-high-performance concrete against blasts: *from materials to structures*.

[10] Yoo, D. Y., Kim, S. W., and Park, J. J. (2017). Comparative flexural behavior of ultra-high-performance concrete reinforced with hybrid straight steel fibers. *Construction and Building Materials*, 132, 219-229.

[11] Huang, L., Xu, L., Chi, Y., and Xu, H. (2015). Experimental investigation on the seismic performance of steel–polypropylene hybrid fiber reinforced concrete columns. *Construction and Building Materials*, 87, 16-27.

[12] Yu, R., Tang, P., Spiesz, P., and Brouwers, H. J. H. (2014). A study of multiple effects of nano-silica and hybrid fibres on the properties of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) incorporating waste bottom ash (WBA). *Construction and Building Materials*, 60, 98-110.

[13] López-Buendía, A. M., Romero-Sánchez, M. D., Climent, V., and Guillem, C. (2013). Surface treated polypropylene (PP) fibres for reinforced concrete. *Cement and Concrete Research*, 54, 29-35.

[14] Zhu, Y. G., Kou, S. C., Poon, C. S., Dai, J. G., and Li, Q. Y. (2013). Influence of silane-based water repellent on the durability properties of recycled aggregate concrete. *Cement and Concrete Composites*, 35(1), 32-38.

[15] Deng, F., Ding, X., Chi, Y., Xu, L., and Wang, L. (2018). The pull-out behavior of straight and hooked-end steel fiber from hybrid fiber reinforced cementitious composite: Experimental study and analytical modelling. *Composite Structures*, 206, 693-712.

[16] Smarzewski, P., and Barnat-Hunek, D. (2018). Property assessment of hybrid fiber-reinforced ultra-high-performance concrete. *International Journal of Civil Engineering*, 16(6), 593-606.

[17] Yoo, D. Y., and Yoon, Y. S. (2016). A review on structural behavior, design, and application of ultra-high-performance fiber-reinforced concrete. *International Journal of Concrete Structures and Materials*, 10(2), 125-142.

[18] Yoo, D. Y., Kim, M. J., Kim, S. W., and Park, J. J. (2017). Development of cost effective ultra-high-performance fiber-reinforced concrete using single and hybrid steel fibers. *Construction and Building Materials*, 150, 383-394.

[19] Wang, H., Sun, X., Wang, J., and Monteiro, P. J. (2016). Permeability of concrete with recycled concrete aggregate and pozzolanic materials under stress. *Materials*, 9(4), 252.

[20] Way, R., and Wille, K. (2012). Material characterization of an ultra-high-performance fibre-reinforced concrete under elevated temperature. *In Proceedings of the 3rd International Symposium on UHPC and Nanotechnology for High Performance Construction Materials*, 565-572.

[21] Abid, M., Hou, X., Zheng, W., and Hussain, R. R. (2019). Effect of fibers on high-temperature mechanical behavior and microstructure of reactive powder concrete. Materials, 12(2), 329.

[22] Hager, I., Mróz, K., and Tracz, T. (2019). Contribution of polypropylene fibres melting to permeability change in heated concrete-the fibre amount and length effect. In IOP Conference Series: *Materials Science and Engineering*, 706(1), 012009.

[23] Wu, L., Lu, Z., Zhuang, C., Chen, Y., and Hu, R. (2019). Mechanical Properties of Nano SiO2 and Carbon Fiber Reinforced Concrete after Exposure to High Temperatures. *Materials*, 12(22), 3773.

[24] Concrete, U. H. P., Schmidt, M., Fehling, E., and Geisenhansluke, C. (2004). Ultra High Performance Concrete (UHPC).

[25] Li, H., and Liu, G. (2016). Tensile properties of hybrid fiber-reinforced reactive powder concrete after exposure to elevated temperatures. *International Journal of Concrete Structures and Materials*, 10(1), 29-37.

[26] BS EN 197-1, (2011). Cement-Part 1: Composition, specifications and conformity criteria for common cements. *British European Standards Specifications*.

[27] ASTM C1240-14, (2014). Standard specification for silica fume used in cementitious mixtures. *ASTM International, West Conshohocken, PA*.

[28] ASTM C33/C33Me, (2018). Standard Specification for Concrete Aggregates. *ASTM International, West Conshohocken, PA*.
[29] ASTM, A. (2017). C138/C138M-17a. Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete, West Conshohocken, PA, USA: *ASTM International*.
[30] ASTM, A. (2012). C143/C143M-12-Standard Test Method for Slump of Hydraulic-Cement Concrete. *USA: ASTM International*.
[31] ASTM, C. (2012). Standard test method for compressive strength of cylindrical concrete specimens.
[32] ASTM C469/C469M-14. Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression; *ASTM International: West Conshohocken, PA, USA, 2014*.
[33] ASTM, C. (2004). 496/C 496M-04. Standard test method for splitting tensile strength of cylindrical concrete specimens, 4, 5.
[34] ASTM C78/C78M-18. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading); *ASTM International: West Conshohocken, PA, USA, 2018.*