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Optimization of Different Properties of Ultra-High Performance Concrete Mixes for Strengthening Purposes

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ABSTRACT

The current research's purpose is to examine how Ultra-High Performance Fiber Concrete (UHPFC) holds up in terms of strength and durability for strengthening purposes. For this reason, the experimental and the theoretical studies in this research attempted to assess different fresh and hardened properties of a variety of ultra-high performance combinations. Steel fibers were utilized to differentiate all of the program's combinations at percentages of 0.25 %, 0.5 %, 0.75 %, 1%, and 1.25 % by volume. Mini flow slump, compressive and flexural strength, ultrasonic pulse velocity, water absorption, and porosity tests were all used to examine the performance of the strength and durability of the material. The findings of this study's trials showed that steel fibers increased the strength of UHPFC. The steel fiber ratio of 1% gave the maximum compressive strength, whereas 1.25 percent yielded the highest flexural strength. Because the fibers function as a bridge, preventing internal breaking, the tensile test results were improved as the proportion of steel fiber rises. Through the use of the multi-objective optimization approach, the optimal ratio of fibers was chosen at the end of the laboratory work since it has the best durability and strength characteristics. Statistical software (Minitab 2018) was used to find the optimal combination of UHPFC that meets all of the requirements. The theoretical selected optimum ratio of 0.77% of fibers obtained from the optimization was evaluated and validated experimentally. The optimized mix provided 90.28 MPa, 14.6 MPa, and 20.2 MPa for compressive, splitting tensile and flexural tests respectively with better durability performance compared to other mixes prepared in this investigation.

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1. Introduction

High strength concrete is widely used in construction projects such as a long span bridges, piles, and huge structures. Because of its complexity, UHPC has taken several years to be used. In the beginning, the evolution of UHPC is back to the 1930s. Eugene Freyssinet applied a pressure to concrete during the setting process, that procedure caused rising in compressive strength. Later on and in the 1960s, the pressure was applied to the concrete in conjunction with a curing by heating using a vacuum mixing method, and the compressive strength reached to 230 MPa (Yudenfreund et al., 1972). Some researchers have studied adding some materials that may improve the properties of high performance concrete for example, (Faried et al., 2021) studied the effect of adding rice husk ash (RHA) on HPC under different temperatures by adding seven types of this material to the concrete to examine the

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mechanical and durability properties. A significant improvement was observed in the residual compressive strength at a temperature of 700 ºC by 1% of (RHA). (Faried et al., 2021) compared different treatment systems, namely internal and standard curing, as well as polyethylene and air curing of HPC mixed with four types of nano-materials (Metakaolin, nano glass waste, rice husk ash and chemically prepared nano RHA). Ratios used were (1%, 2%, and 3%) by weight of cement. Velocities of wave transmission in addition to the compressive strength were conducted. The results were approximately similar in performance for the four curing systems. They found that the polyethylene curing had a slight negative effect on the resulted properties. Compressive strength increased by (17%, 24%, 14%, and 13%) under the influence of internal curing for each of the rice husk ash, waste glass, Metakolin, and chemically prepared RHA respectively. In contrast, the absorption decreased under the influence of polyethylene treatment for each of the four aforementioned materials by about (84%, 60%, 48% and 60%) respectively.

A pressure of 50 MPa and an exceptionally high temperature (200°C) were used to get a concrete with a 510 MPa compressive strength. The natural material that used in concrete was contained very fine reactive materials, therefore UHPC was initially known as Reactive Powder Concrete (RPC) (Richard & Cheyrezy, 1995). Recently, (Tayeh et al., 2019) conducted a research to study the mechanical properties of HPC, as well as to compare the resulted properties with ordinary concrete. The fibers contents were 2% to 3% and a water-to-cement ratio was less than 0.2. (Amin & Tayeh, 2020), used ceramic waste as coarse aggregate, as this step aims to fill the shortage of material in the site, as well as to reduce this waste. Eleven mixtures were designed with 10%, 20%, 30% of silica and kaolin. Results showed a significant improvement in the compressive strength at the age of 28 days and the maximum compressive strength achieved was 146.6 MPa. (Saad et al., 2020) worked on increasing the tensile strength of high-strength concrete by adding plant-based fibers such as banana tree fiber and palm leaf sheath fiber. He designed three concrete mixtures that contain banana fiber while others contained a combination of the two types. The tensile strength increased by 2% for the combined mixtures than for the mixtures containing banana fibers only, and the percentages used were (1%, 2% and 3%) with aspect ratio of 100.

Due to the use of short discontinuous steel fibers with Ultra-High Performance concrete in cement-based composite, a very high compressive strength of about 150 MPa and a high tensile strength of 6.2 to 11.7 MPa compared to ordinary concrete were obtained (de Larrard & Sedran, 1994). In order to reduce brittleness and enhance energy absorption capacity, steel fibers are added to the paste. The name Ultra-High Performance Fiber Reinforced Concrete (UHP-FRC) is used in the wide world (Rossi et al., 2005), (Habel et al., 2006). The development of homogenous and dense matrix is a key element in the development of UHPC. The elimination of coarse aggregate particles to reduce the influence of the interfacial transition zone between cement paste and aggregate, which contains micro-cracking, is one of the key distinctions between UHPC and conventional concrete. To achieve high strength and durability, a low water to cementitious materials ratio (w/cm) is required (Wang et al., 2012). Due to the obvious high binder concentration, the UHPC has an explosive brittle failure and a proclivity for micro cracking, both of which are connected to the significant auto-genous shrinkage. Steel fibers are incorporated to mixture design for this reason (Shaheen & Shrive, 2006).

UHPC has grown in popularity in many countries over the last two decades, with applications ranging from building components, bridges, architectural features, strengthening and repairing due to rehabilitation, vertical components such as windmill towers and utilities towers to oil and gas industry applications, off-shore structures, hydraulic structures, and overlay materials. UHPC was used in a variety of nations, including Australia, Austria, Canada, China, the Czech Republic, France, Germany, Italy, Japan, Malaysia, the Netherlands, New Zealand, Slovenia, South Korea, Switzerland, and the United States (Voo et al., 2017).

The performance of mechanical concrete properties was improved to get high strength concrete that achieved through changing the cement ratio, water content and using more additives to mixture such as fibers. When the strength of the concrete increases, the elastic modulus increases as well, lowering the creep coefficient. This is why high strength concrete tends to be more prone to resisting pressure than low strength concrete (Mehta & Monteiro, 2014).

Steel fibers have been manufactured in various geometrical shapes, such as the hooked end, crimped, deformed end, and deformed wire. The hooked end is being the most common type of steel fiber utilized in the market. Steel fiber has been proved to be the ideal combination for high strength concrete to create the maximum mechanical strength and durability (Ezeldin & Balaguru, 1992). To get high strength concrete that contain steel fiber, it prefer to improve the concrete workability by using amount or volume of superplasticizer (SP). The minimum 150mm-160mm of flow rates of fresh UHPC can be maintained using SP (Yao et al., 2003) .The results prove that the SP is primary function to regulate the water binder ratio. Also the studies show that the inclusion of steel fiber enhanced the modulus of rupture, while the polypropylene fiber produced the lowest modulus of rupture (Yao et al., 2003).

Steel fiber improve the flexural strength and ductility of concrete. The short steel fiber could be bridging the components of concrete to prevent the fracture growth. The steel fiber could increase the strength of harden concrete and reduce the voids and cracks. (Swamy, 1974),(Chunxiang, 2000).

Recently, the numbers of bridges that required retrofitting, or potentially replacing owing to environmental factors, has increased. Further increase is expected in the near future due to the end of their design lifespan. Thus, Ultra-high performance concrete can be used to repair and retrofit these bridges and various other concrete structural component (Farzad et al., 2019) , (Valikhani et al., 2020). The development of Ultra-High-Performance fiber concrete with a compressive strength of more than 100 MPa and enhanced its durability is a significant step forward in the concrete industry. This high-performance material has a variety of intriguing uses. It enables the development of environmentally friendly and cost-effective structures with an unusually thin shape. Because of its great strength and ductility, it is the ideal building material for bridge decks, storage halls, thin-walled shell buildings, and heavily loaded columns. Aside from its enhanced strength qualities, its exceptional resistance to all types of corrosion is another step toward zero-maintenance construction (Askar et al., 2017). The main idea of this study is to produce UHPFC, with optimum strength and durability properties. This research work is a small part of a big project aiming to strength and repair of corroded concrete columns and studying their compression performance after retrofitting. To achieve that the experimental and theoretical programs in the first stage have been designed to include strength and durability tests for the produced UHPC. The optimum combination of UHPC will be used for strengthening purposes for the next stage of the project.

2. Research Significance

It is believed that this work might add a new knowledge in preparing and selecting the UHPC mixes for strengthening purposes. The previous reviewed work considers the preparation of these mixes only by selecting a fixed steel fibers ratio without optimizing the properties of the resulted concrete. In this work, the different resulted properties in terms of strength and durability were optimized to give the best performance for these two aspects.

3. Experimental Work

3.1 Materials

3.1.1 Cement

In this study, Ordinary Portland Cement OPC was used. The properties of this cement were identical to the Iraqi standards and Portland Cement Standard Specification (Standard Specification for Portland cement) (IQS NO. 5, 1984). Table 1 shows the physical properties of cement used while Table 2 clarifies the chemical compositions.

Table 1: Physical properties of cement

Type of Test	Property	Iraqi specification limit IQ5 5/1984[59]
Initial setting time(minutes)	100	a maximum of 45 min
Final setting time (minutes)	355	a maximum of 600 min
Fineness (m^2/ kg) by Blain method	295	a minimum of 230
Compressive strength at 3 days (MPa)	20	a minimum of 15 (MPa)
Compressive strength at 7days (MPa)	25	a minimum of 23 (MPa)

Table 2: Chemical composition of cement

Oxides	percentage by weight	Iraqi specification limit IQS 5/1984[59]
CaO	66.26	
Fe_2O_3	3.73	

SiO_2	19.11	
Al_2O_3	6.42	
MgO	1.45	a maximum of 5%
SO_3	1.85	a maximum of 2.5%
Loss on ignition	2.2	a maximum of 4%
Insoluble residue	0.96	a maximum of 1.5%
Main compounds		
C3A	2.9	Less or equal 3.5%
C2S	8.52	
C3S	61.8	
C4AF	7.07	

3.1.2 Micro Steel Fibers

The used steel fiber's type was straight with 0.2 mm diameter and 15mm length free of any contaminated substance or rust as shown in Fig.1 The properties of steel fibers were checked and tested according to (ASTM, 2009). Table 3 shows the properties of steel fiber used.

Figure1. steel fiber

Table 3: Micro steel fiber properties as provided by the producer

Surface	**Brass coated**
Relative Density	7800 kg \m^3
Tensile Strength	Minimum 2600 MPa
Form	Straight
Melting Point	1500 ºC
Average Length	15mm
Diameter	0.2mm
Aspect Ratio (Lf/Df)	75
Type	WSF0213

3.1.3 Silica fume

The present study used silica fume with a specific gravity of 2.2. Physical and chemical analysis of the used silica fume was done at the Ministry of Science and Technology – Iraq according to (ASTM, 2009). The properties of silica fume are shown in Table 4.

Table 4: Properties of silica fume

	Limit-ASTM-C1240	Silica used	Constituent	Content (%) (X R D)
Surface area	≥15m^2 /g	27.3 m^2 /g	SiO_2	91
Moisture content	Max3%	0.6%	Fe_2O_3	0.2
Loss of ignition	0.6%	Max6%	Al_2O_3	0.2
Total silica	Min.85%		CaO	0.5
			MgO	0.4
			K_2O	0.5
		0.05	N_2O	0.2
			SO3	0.15
			C1	0.01
			H2O	0.5

3.1.4 Super plasticizer

Super plasticizer with the tradenameSikaViscoCrete5930, which is super plasticizer for concrete and mortar of the third generation, was used to modify the fresh properties of the mixes produced in the present study. It meets the requirements for super plasticizer specified by (ASTM C494, 2013). The density of this type is 1.08kg/liter with a pH value of 8.0±1.0.

3.1.5 Fly ash

Class F fly ash with a specific gravity of 2.09 g/cm3 and Blaine fineness of 379 m^2/kg was used in the present study which was derived from bituminous and anthracite coals and consist primarily of alumino-silicate glass with quarts, mullite and magnetite. Table 5 shows the chemical composition of the fly ash used.

Table 5: Chemical composition of fly ash used

Chemical entity	Content by mass %
SiO2	38.8
Al2O3	14.7
Fe2O3	19.48
CaO	18.1
MgO	3.3
SO3	1.5
K2O	1.79
TiO2	1.02
MnO	0.16
BaO	0.27
SrO	0.11

3.1.6 Aggregate

Natural sand from nearby regions was used in this study. It has a sleek finish and a rounded shape, with a maximum size of 4.75 mm. Gravel crushed with a maximum size of 10 mm was used as coarse aggregate. The grading test results showed that both fine and course aggregate were confirmed to the Iraqi standards (IQS NO. 45, 1984) as shown in Fig.2.

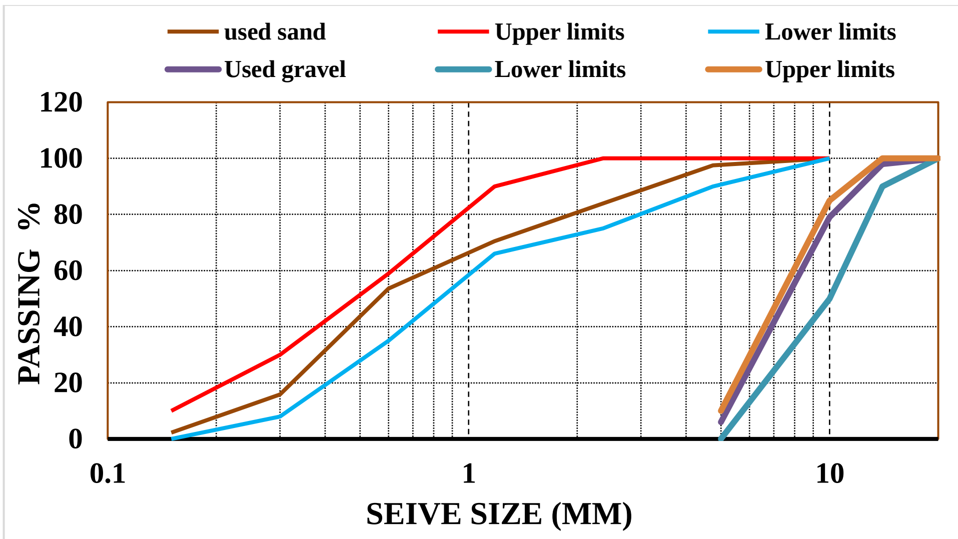


Figure 2. Grading curves for the aggregate used

3.2 Mix design

UHPFC mixes can be designed like conventional concrete but these mixes contain higher volume of fine aggregates and cement. In this study, the reference UHPC mix and other combinations with steel fibers were designed by absolute volume method due to the use of different ratios of steel fibers by volume .The cement content was (650 kg/m³) with silica fume and fly ash of (160 kg/m³) and (300 kg/m³) respectively . The water to cementitious materials (w/cm) ratio is kept constant (0.18) for all mixes with the aid of using SP and the combined aggregate content was (957 kg/ m³). Admixtures of high range water reducing, superplasticizer SP, was added at percentage of (2.4%) by weight of cement for all the studied mixes. These mixes combined with micro steel fiber by ratios from 0.25% to 1.25 % are shown in Table 6.

Table 6: Mix design of Ultra-High Performance Concrete UHPC mixes

Mix No.	w/c ratio	Mix proportions (kg/m^3)							% Steel fiber	Compressive strength MPa 28 days
		C	C.A	F.A	W	SF	FA	SP %		
1	0.18	650	50	907.5	200	160	300	2.4	0.25	76.156
2	0.18	650	50	907.5	200	160	300	2.4	0.5	72.16
3	0.18	650	50	907.5	200	160	300	2.4	0.75	83.57
4	0.18	650	50	907.5	200	160	300	2.4	1	73.36
5	0.18	650	50	907.5	200	160	300	2.4	1.25	83.82

C: cement, C.A: coarse aggregate, F.A: fine aggregate, W: water, SF: silica fume, FA: fly ash, SP: superplasticizer

3.3 Testing program

The specimens of UHPFC mix were prepared using cylindrical steel mold of size (100×200mm) ,a cube (100×100) and prisms of size (40 ×40×160 mm) for most testing which are carried out throughout this work. The mini flow table test was conducted to measure the workability of all fresh UHPFC mixtures according to ASTM C1437-01 (Bauer et al., 2007). The samples are withdrawn from the modulus after 24 hours from casting them. Each sample of UHPFC is put in curing water for 7and 28 days. Compressive strength measures the quality and uniformity of UHPFC. The compressive strength is determined according to (ASTM C-39. (Aggregates, 2014). All the cylinder specimens are tested under compression using the (ELE) testing machine, with capacity of 1800 KN. The splitting tests were carried out with ASTM Standard test C496/C496M-11 (ASTM, 2011). The UHPFC prisms with dimensions of (40×40×160) mm were employed according to (ASTM C1609, 2012) to measure the modulus of rupture for UHPFC tested by 50 KN capacity hydraulic machines (EN, 2009). Porosity is an inherent characteristic of hardened concrete because it has a significant impact on concrete durability and explains the transport mechanisms via a concrete body, such as aggressive agent entrance. The Porosity and water absorption tests method are used in this investigation according to ASTM C 642 (Materials, 2013). Also the Ultrasonic plus velocity test is another test that affects the homogeneity of the mixture .This examination was conducted in accordance with the ASTM C597 (ASTM, 2009).

4. Results and Discussion

4.1Flow table test

After preparing the mixes with the proportions, flow table test was carried out immediately after mixing. The flow table test was carried out to ensure that the mixes satisfy the desired workability requirements with a w/cm ratio of (0.18). Table (7) shows the results of flow table test for each mix. The results ranged from 230 mm for mix with steel fiber ratio of 0.25% to 205 mm for 1.25 % while reference mixture was 275 mm. Micro steel fibers used for the UHPC mixture caused a decrease in the workability of mixtures as shown in Table 7. The result show, the different values for flow table test which reduced with the increase of fibers contents. This might be attributed to the role of steel fibers to restrict the flow of the mix. The addition of steel fibres to UHPC mixes can reduce the flow significantly especially with high contents (Yu et al., 2014). (Saad et al., 2020) reached a similar conclusion for natural fibers in high strength concrete. It was found that the flow in the presence of the these fibers at percentages of 1%, 2% and 3% decreased by 7.7%, 11.5% and 19.2%, respectively.

Table 7: Mini slump flow for UHPC mixes

Steel fibers ratio %	Flow table result (mm)
0	275
0.25	230
0.50	223
0.75	220
1.00	210
1.25	205

4.2 Compressive, flexural and splitting tensile strength results

Fig.3 shows the results of the compressive strength of UHPC mixes at 7 and 28 days while Figs. 4 and 5 show the flexural and splitting strength results at 28 days. It is noticeable from Figure (3) that the compressive strength value fluctuates with the change in the fibers ratio for the UHPC mixes. However, the highest value was achieved (83.82) MPa at age of 28 days) when the fiber ratio is 1.25 %. As well, for the flexural test, the highest value (21.76 MPa) was maintained at a steel fibers' ratio of 1.25 % as shown in Figure (4). This is the normal for fibers action in increasing the sample's tolerance to flexural. Flexural strength increased sharply as the volume of the fibres increased (Velayutham & Cheah, 2014) (Kim et al., 2011). However, beyond a certain value, the strengths (compressive and flexural) could be decreased and this might be attributed to the balling and agglomeration effects of fibers at high ratios. As for the tensile test, the value increases with the increase of the fibers, as shown in the

Figure (5). This is because of the fibers action as a bridge that blocks the internal cracks. This was also proved by other researcher through studying the mechanical properties of high-strength concrete and the effect of fibers on it (Aziz & Ahmed, 2012).

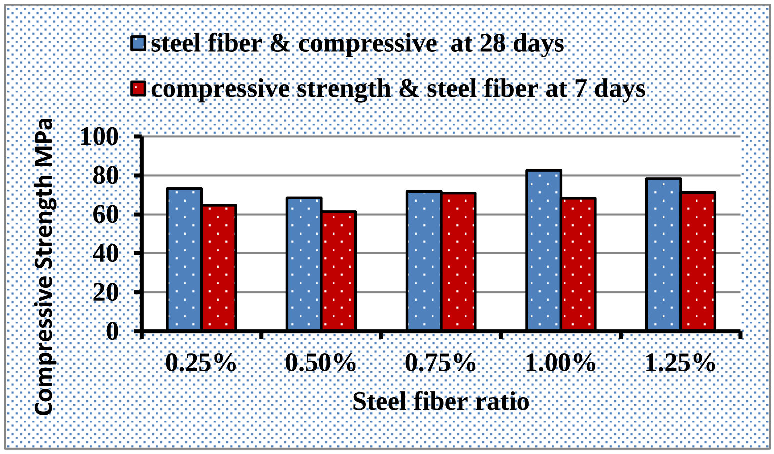


Figure 3. Compressive strength values for various amounts of steel fibers at 7 and 28 days

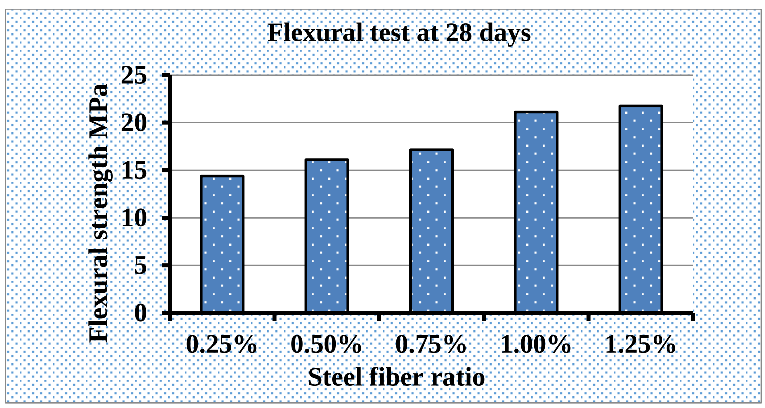


Figure 4. Flexural test values for various amounts of micro steel fibers

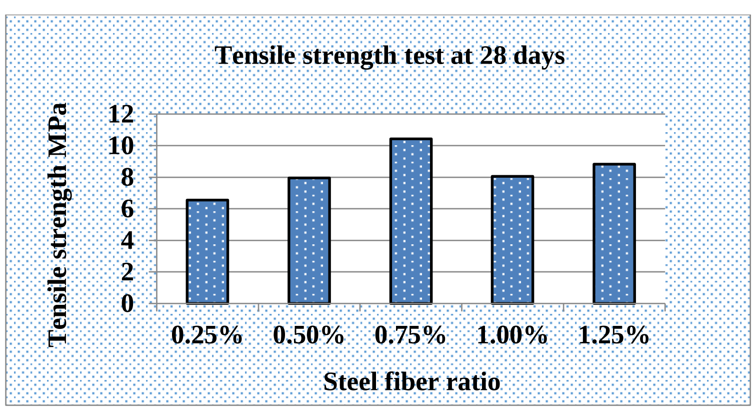


Figure 5. Splitting tensile test values for various amounts of micro steel fibers

However, the maximum achieved splitting tensile strength was 10.4 MPa at a fiber ratio of 0.75 % in this study. Figs. 6, 7 and 8 shows the damage and failure modes of some selected UHPC mixes for compressive, flexural and splitting tensile tests respectively. It is clearly observed from the Figs. above that the UHPC mixes containing fibers showed a gradual failure as compared to control mix especially at flexural strength test.

Figure 6. Damage and failure mode after compressive strength test for the optimized mix

Figure 7. Damage and failure mode after flexural strength test for the optimized mix

Figure 8. Damage and failure mode after tensile strength test for the optimized mix

4.3 Porosity and water absorption results

In fact, as shown in the Figure (9), the value of the porosity increases with the increase in the percentage of steel fiber content. This increase might be due to the fact that the steel fiber formed voids inside the sample, which certainly led to an increase in the porosity (Noroozian et al., 2009). These voids can be as a result of interrupted water beneath the fibers during the compaction process. The highest value of porosity (3.2%) was obtained for steel fiber ratio of 1.25 % as shown in Figure 9.

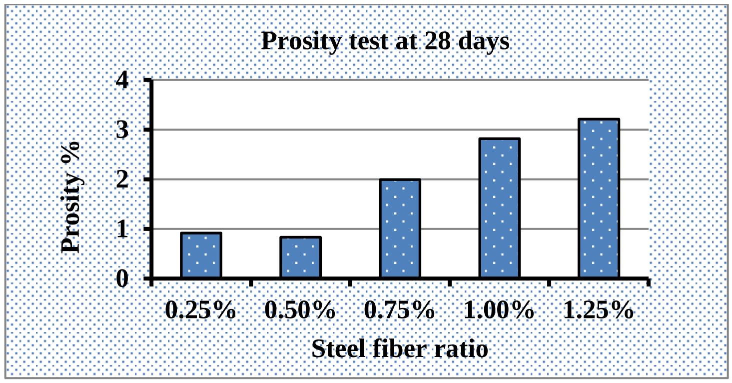


Figure 9. Porosity and micro steel fiber relationship for UHPC mixes

In the same way of the porosity results, the water absorption results' also affected by the amount of fibers UHPC mix as shown in Figure (10).

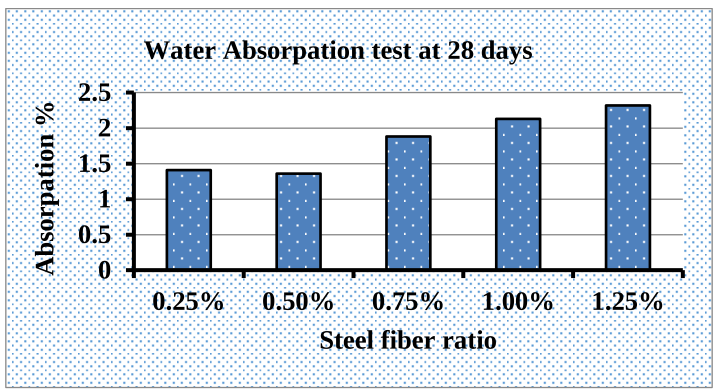


Figure 10. Water absorption and micro steel fiber relationship for UHPC mixes

4.4 Ultrasonic plus velocity test results

Figure (11) presents Ultrasonic Pulse Velocity (UPV) of ultra – high performance concrete mixes with different ratios of steel fiber. It was observed that the Ultrasonic Pulse Velocity decreased with the increase of steel fiber ratio (Ali & Almawla, 2020). The faster the waves pass, the better the mixture. It is also noted that the value of 0.5% gives the highest speed for the passage of waves.

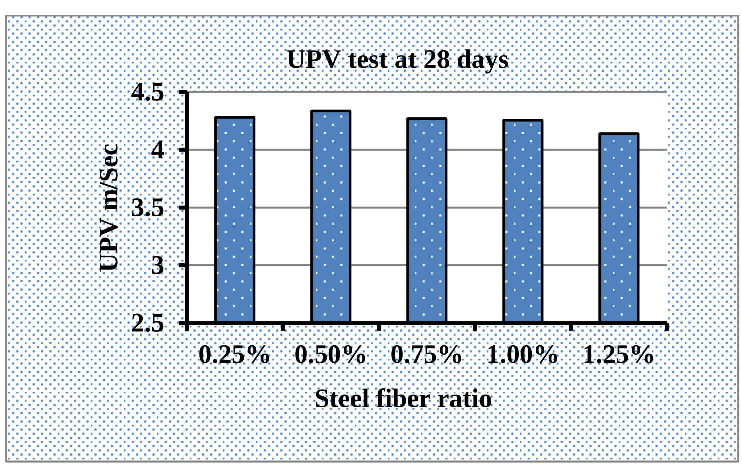


Figure 11. Ultrasonic plus velocity test values for various amounts of micro steel fiber for UHPC mixes

4.5 Optimization of the properties of UHPFC mixes and validation

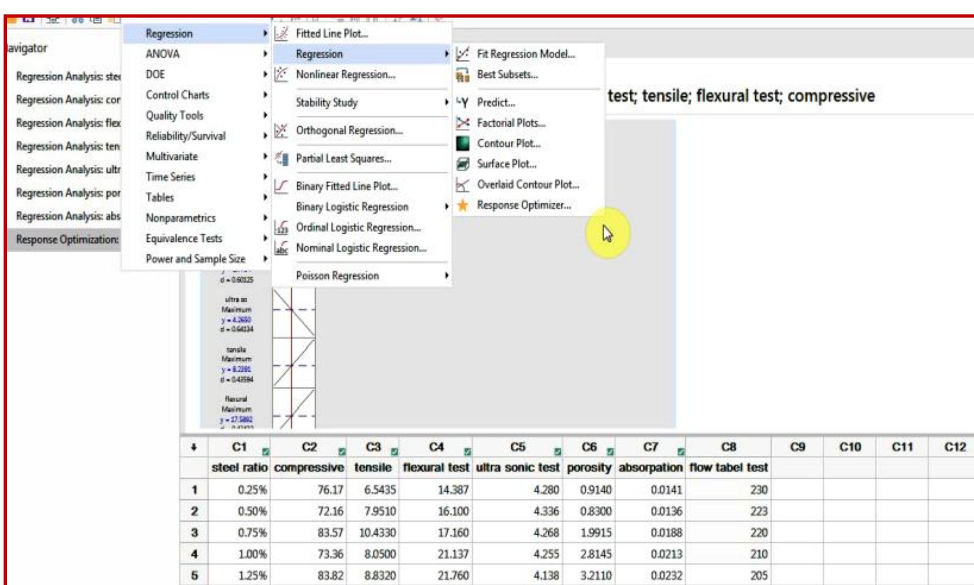
From the above reviewed and evaluated initial experimental results, it was concluded that there was no optimum fibers content that gave the best fresh and hardened properties simultaneously. Accordingly, for sure, there is an optimum content of fibers between the studied ratios that could give the best performance for an optimal UHPC mix. This mix could have the highest flow, highest compressive, flexural and tensile strengths, highest UPV and lowest porosity and absorption. Thus, a theoretical multi objectives optimization was performed for all the responses (tested properties) to find this optimum mix.

The optimum selection of the mixture that gives the best specifications in terms of strength and durability was done using a statistical program (Minitab 2018). The responses used for the optimization purpose is summarized in Table8. The optimization is set to give the maximum values of preferable properties and the minimum for the unwanted properties such as porosity and absorption. Through the theoretical analysis performed, a 0.77% ratio was specified as an optimal ratio. The principle of the programs work is by entering the inputs (fibers content) as dependent variable and (tested properties/responses) as independent variables shown in Table 8. The final output after doing the optimization represents the optimum ratio of steel fiber that gives the highest and lowest values as explained above using the desirability function approach.

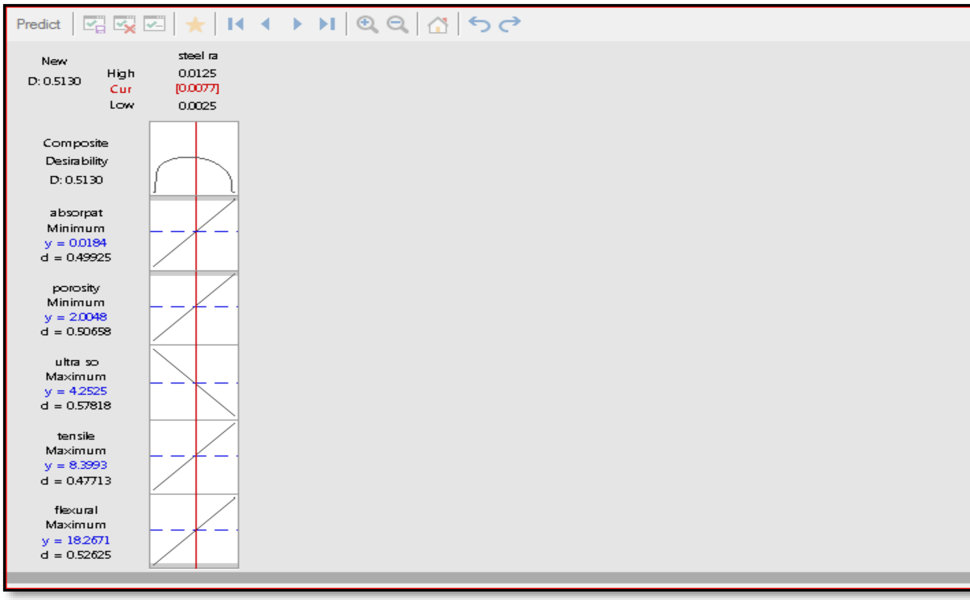
Table (8): Summary of responses used for optimization

V_f %	Flexural MPa	Compressive MPa	Tensile MPa	Absorption %	Porosity %	Flow (mm)	UPV m\s
0.25	14.39	76.2	6.5	1.4	0.91	230	4.28
0.5	16.1	72.2	7.95	1.36	0.83	223	4.34
0.75	17.16	83.6	10.4	1.88	1.99	220	4.27
1%	21.14	73.4	8.05	2.13	2.81	210	4.26
1.25	21.76	83.8	8.8	2.32	3.21	205	4.14

The procedure used for optimization the initial experimental results using Minitab software and the final output results are shown in Figure 12 a and b respectively.



(a)



(b)

Figure 12. (a) and (b) steps of choosing the best mix by Minitab

In order to validate the theoretical optimization performed, it was decided to produce and test this optimized mix experimentally. The experimental results of the obtained mix with 0.77% fibers content showed that it gave the best performance among the UHPC mixes prepared in this investigation in terms of fresh properties, strength and durability. As compared to 1% and 1.25% fiber contents, for example, the optimum mix shows increases or approximately similar results of the most tested properties as shown in Table 9. Thus, it will be selected for the strengthening corroded steel columns for the next stage of the whole project as mentioned at the end of the introduction part.

Table (9) Results and experimental validation of optimum mix

V_f %	Flexural MPa	Compressive MPa	Tensile MPa	Absorption %	Porosity %	Flow (mm)	UPV m\s
1%	21.14	73.4	8.05	2.13	2.81	210	4.26
1.25	21.76	83.8	8.8	2.32	3.21	205	4.14
0.77 Optimized Mix	20.2	90.28	14.6	2	1.8	215	4.14

5. CONCLUSIONS

The most obvious findings to be raised from this study can be summarized as follow:

- The results indicated that increasing the micro steel fiber more than (1.25%) could increase flexural strength because the steel fiber worked as a bond between the sample particles prevent it from crack.
- Compressive strength increased with the amount of steel fiber; however, this increase is insignificant in comparison to tensile test with same ratio.
- The results indicate that the splitting strength increased with the increase of steel fiber content compared to the reference UHPFRC.
- The best theoretical percentage of steel fiber was 0.77% that could give good properties in terms of strength and durability for UHPFRC concrete. These results was obtained by doing optimization via statistical software (Minitab 2018).
- The above theoretical value was validated by doing the same tests for this mix and the experimental results of it shows that it gave the best performance among the other selected ratios of steel fibers for UHPC mixes.

- The UHPFC mixture with the optimum steel fibers content (0.77%) could be used for strengthen the corroded concrete columns where it gave a 90.28 MPa , 14.6, 20.2 for compressive and tensile, flexural respectively. The UPV for this mix was 4.14 m/s while water absorption and porosity were only 2% and 1.8%.

REFERENCE

Aggregates, A. I. C. C. on C. and C. (2014). Standard test method for compressive strength of cylindrical concrete specimens. ASTM international.

Ali, S., & Almawla, A. (2020). Production and Properties of Self-Compacting Lightweight Concrete Containing Waste Plastic Fibers. University of Anbar.

Amin, M., & Tayeh, B. A. (2020). Effect of using mineral admixtures and ceramic wastes as coarse aggregates on properties of ultrahigh-performance concrete. Journal of Cleaner Production, 123073. https://doi.org/10.1016/j.jclepro.2020.123073

Askar, L. K., Tayeh, B. A., Abu Bakar, B. H., & Zeyad, A. M. (2017). Properties of ultra-high performance fiber concrete (UHPFC) under different curing regimes. International Journal of Civil Engineering and Technology (IJCIET), 8(4).

ASTM. (2009). Standard Specification for Pulse Velocity Through Concrete. Annual Book of ASTM Standards, Note 2, 6–9. https://doi.org/10.1520/C0597-09.2

ASTM, C. (2011). Standard test method for splitting tensile strength of cylindrical concrete specimens. In C496/C496M-11.

ASTM C1609. (2012). Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete. ASTM Standard Book, i(C 1609/C 1609M-05), 1–8. https://doi.org/10.1520/C1609

ASTM C494. (2013). ASTM C494 : Standard Specification for Chemical Admixtures for Concrete. Annual Book of ASTM Standards, 10.

Aziz, O. Q., & Ahmed, G. H. (2012). Mechanical properties of Ultra High Performance Concrete (UHPC). American Concrete Institute, ACI Special Publication, 289 SP, 331–346. https://doi.org/10.14359/51684273

Bauer, E., de Sousa, J. G. G., Guimarães, E. A., & Silva, F. G. S. (2007). Study of the laboratory Vane test on mortars. Building and Environment, 42(1), 86–92.

Chunxiang, Q. (2000). Cement & Concrete Composites. 21(1999), 73–81.

de Larrard, F., & Sedran, T. (1994). Optimization of ultra-high-performance concrete by the use of a packing model. Cement and Concrete Research, 24(6), 997–1009.

EN, B. S. (2009). 12390-3: 2009. Testing Hardened Concrete. Compressive Strength of Test Specimens, 19.

Ezeldin, A. S., & Balaguru, P. N. (1992). Normal-and high-strength fiber-reinforced concrete under compression. Journal of Materials in Civil Engineering, 4(4), 415–429.

Faried, A. S., Mostafa, S. A., Tayeh, B. A., & Tawfik, T. A. (2021). The effect of using nano rice husk ash of different burning degrees on ultra-high-performance concrete properties. Construction and Building Materials, 290, 123279. https://doi.org/10.1016/j.conbuildmat.2021.123279

Farzad, M., Shafieifar, M., & Azizinamini, A. (2019). Experimental and numerical study on an innovative sandwich system utilizing UPFRC in bridge applications. Engineering Structures, 180, 349–356.

Habel, K., Viviani, M., Denarié, E., & Brühwiler, E. (2006). Development of the mechanical properties of an ultra-high performance fiber reinforced concrete (UHPFRC). Cement and Concrete Research, 36(7), 1362–1370.

IQS NO. 45, 1984. (1984). Aggregate from Natural Sources for Concrete and Construction. Central Agency for Standardization and Quality Control, Baghdad, IQS, 45.

Kim, D. J., Park, S. H., Ryu, G. S., & Koh, K. T. (2011). Comparative flexural behavior of Hybrid Ultra High Performance Fiber Reinforced Concrete with different macro fibers. Construction and Building Materials, 25(11), 4144–4155. https://doi.org/10.1016/j.conbuildmat.2011.04.051

Materials, A. S. of T. (2013). ASTM C642 :Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, ASTM International, United States. Annual Book of ASTM Standards, March, 1–3. https://doi.org/10.1520/C0642-13.5.

Mehta, P. K., & Monteiro, P. J. M. (2014). Concrete: microstructure, properties, and materials. McGraw-Hill Education.

Menna, C., C, M., Sgobba, S., Asprone, D., & A, P. (2016). Structural Behavior of Strengthened RC Columns Using High Performance Fiber Reinforced Concrete. 4th International Symposium on UHPFRC Construction Materials , At University of Kassel, Kassel, 1(December), 1–16.

Noroozian, R., Abedi, M., Gharehpetian, G. B., & Hosseini, S. H. (2009). Ar ch ive of ch. Iranian Journal of Electrical & Electronic Engineering, 5(2), 131–142.

Richard, P., & Cheyrezy, M. (1995). Composition of reactive powder concretes. Cement and Concrete Research, 25(7), 1501–1511.

Rossi, P., Arca, A., Parant, E., & Fakhri, P. (2005). Bending and compressive behaviours of a new cement composite. Cement and Concrete Research, 35(1), 27–33.

Saad, M., Agwa, I. S., & Abdelsalam, B. A. (2020). Improving the brittle behavior of high strength concrete using banana and palm leaf sheath fibers. Mechanics of Advanced Materials and Structures, 0(0), 1–10. https://doi.org/10.1080/15376494.2020.1780352

Shaheen, E., & Shrive, N. G. (2006). Optimization of mechanical properties and durability of reactive powder concrete. ACI Materials Journal, 103(6), 444.

Swamy, R. N. (1974). THE TECHNOLOGY OF STEEL FIBRE REINFORCED CONCRETE FOR PRACTICAL APPLICATIONS. Proceedings of the Institution of Civil Engineers, 56(2), 143–159.

Tayeh, B. A., Aadi, A. S., Hilal, N. N., Bakar, B. H. A., Al-Tayeb, M. M., & Mansour, W. N. (2019). Properties of ultra-high-performance fiber-reinforced concrete (UHPFRC) - A review paper. AIP Conference Proceedings, 2157(September). https://doi.org/10.1063/1.5126575

Valikhani, A., Jahromi, A. J., Mantawy, I. M., & Azizinamini, A. (2020). Experimental evaluation of concrete-to-UHPC bond strength with correlation to surface roughness for repair application. Construction and Building Materials, 238, 117753.

Velayutham, G., & Cheah, C. B. (2014). The effects of steel fibre on the mechanical strength and durability of steel fibre reinforced high strength concrete (SFRHSC) subjected to normal and hygrothermal curing. MATEC Web of Conferences, 10, 0–8. https://doi.org/10.1051/matecconf/20141002004

Voo, Y. L., Foster, S., & Pek, L. G. (2017). Ultra-High Performance Concrete—Technology for Present and Future. Proceedings of the High Tech Concrete: Where Technology and Engineering Meet, Maastricht, The Netherlands, 12–14.

Wang, C., Yang, C., Liu, F., Wan, C., & Pu, X. (2012). Preparation of ultra-high performance concrete with common technology and materials. Cement and Concrete Composites, 34(4), 538–544.

Yao, W., Li, J., & Wu, K. (2003). Mechanical properties of hybrid fiber-reinforced concrete at low fiber volume fraction. Cement and Concrete Research, 33(1), 27–30.

Yu, R., Spiesz, P., & Brouwers, H. J. H. (2014). Mix design and properties assessment of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC). Cement and Concrete Research, 56, 29–39. https://doi.org/10.1016/j.cemconres.2013.11.002

Yudenfreund, M., Odler, I., & Brunauer, S. (1972). Hardened portland cement pastes of low porosity I. Materials and experimental methods. Cement and Concrete Research, 2(3), 313–330.