Sebha University Journal of Pure & Applied Sciences Vol.23 No. 1 2024
DOI: 10.51984/jopas.v23i1.2679

مجلة جامعة سبها للعلوم البحتة والتطبيقية
Sebha University Journal of Pure & Applied Sciences

Journal homepage: www.sebhau.edu.ly/journal/jopas

Producing Ultra-High Strength Concrete Using Available Conventional Materials in Egypt

Seleem S. E. Ahmad[a], *Mohamed Khalifa Bneni[b], Khalid Ali Gleim[b], and Farah Mechail[a]

[a]Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
[b]Faculty of Engineering, University of Zawia, Zawia 16418, Libya

Keywords:
Ultra-high strength concrete
Compressive strength
Superplasticizer
Silica fume

ABSTRACT

In this study, three trials were performed to obtain an Ultra-High Strength Concrete mix using widely available aggregates, mineral and chemical admixtures, then curing the specimens using a regular regime in clear water, also to observe the diversities of results of compressive strength test for both the cube and the cylinder shapes. For this purpose, three sizes of cubic molds having 70-, 100-, and 150-mm edge length and three sizes of cylindrical molds having dimensions (Ø 100mm x 150 mm), (Ø 100 mm x 200 mm) and (Ø 150mm x 300 mm) were used. The results of the compressive strength test as per ASTM C 39 showed a slight difference between 70- and 100-mm edge length cubes results. Whereas those of 150 mm cubes achieved a significantly higher result, the three sizes of the cylindrical shape have a minimal difference between the upper and lower results, not exceeding 9 %.

إنتاج خرسانة فائقة المقاومة باستخدام المواد التقليدية المتاحة في مصر

سليم صالح السيد أحمد[1] و*محمد خليقة بنيني[2] و خالد علي قليم[2] وفرح ميشيل[1]

[1]كلية الهندسة ، جامعة الزقازيق ، الزقازيق 44519 ، مصر
[2]كلية الهندسة ، جامعة الزاوية ، الزاوية 16418 ، ليبيا

الكلمات المفتاحية:
الخرسانة فائقة المقاومة
مقاومة الضغط
الملدن
غبار السيليكا.

الملخص

في هذه الدراسة، تم إجراء ثلاث تجارب للحصول على خليط خرساني فائق القوة باستخدام ركام متاح ومنتشر علي نطاق واسع ومضافات معدنية وكيميائية، ومعالجة العينات باستخدام النظام العادي في الماء الصافي، وكذلك ملاحظة تنوع نتائج اختبار مقاومة الانضغاط لـ كل من أشكال المكعب والأسطوانة. لهذا الغرض، تم استخدام ثلاثة أحجام مختلفة من القوالب المكعبة بطول حافة 70 و100 و150 مم وثلاثة أحجام من القوالب الأسطوانية بأبعاد (Ø 100 مم × 150 مم)، (قطر 100 مم × 200 مم) و (قطر 150 مم × 300 مم). أظهرت نتائج اختبار مقاومة الانضغاط وفقًا لمعيار ASTM C 39 فرقًا بسيطًا بين نتائج مكعبات طول الحافة 70 و100 مم، بينما حققت تلك المكعبات 150 مم نتيجة أعلى، في حين أن الأحجام الثلاثة للشكل الأسطواني لها فرق ضئيل بين النتائج العلوية والسفلية لا تتعدى 9٪.

Introduction

Ultra-High-Performance Concrete (UHPC) is a relatively new powder concrete. According to [1], UHPC is a kind of concrete that features compressive strength over the C100/115 class. Since UHPC has a very low water/cement ratio (W/C) for good workability, the best possible solution is the use of the latest admixture type of superplasticizer, namely polycarboxylate ether (PCE). Using a lower w/c ratio, to the improvement of compressive strength. The w/c ratio is usually between 0.4 and 0.6 in conventional concrete and not less than 0.4 to

*Corresponding author.
E-mail addresses: mo.bneni@zu.edu.ly, (S. S. E. Ahmad) seleemahmad62@yahoo.com, (K. Gleim) K.gleim@ zu.edu.ly, (F. Mechail) farahmike58@gmail.com
Article History : Received 30 August 2023 - Received in revised form 14 May 2024 - Accepted 22 May 2024

obtain a good hydration and a workable concrete mix. In contrast, the w/c ratio of about 0.15 to 0.30 is used in reactive powder concretes to obtain a stronger, denser material structure [2], also Shi [3] reported it is well known that the decrease in w/c will low porosity and increase strength of hardened cement based-materials [4,5]. The perfect water-to-binder ratio of reactive powder concretes limits between 0.14 and 0.2, instead of 0.4-0.5 of traditional concrete. On the other hand, superplasticizers are selected and used for the production of high-quality UHPC.

One of the importance of concrete properties is the compressive strength, especially in the case of structural design. Therefore, the use of this value has become problematic as a result the control sample shapes and sizes may be different countries [6]. Using test samples with different sizes and shapes may result in various values of concrete compressive strength. Thus, appropriate conversion factors have to be established to provide the necessary input for the classification of UHPC and conformity tests. Because maintaining standard sample sizes of UHPC may cause problems due to the limited capacity of current testing machines, test samples with reduced sizes appear to be favorable [7]. However, the common notion that the compressive strength of powder concretes is a unique material property is an erroneous one since the compressive strength changes based on specimen sizes and shapes due to its fracture characteristics [8]. Coarse aggregate is excluded in many UHPC mixture ratios. This exclusion decreases the micro-cracks that are present in the coarse aggregate and the interfacial growth region between the paste and coarse aggregate. These micro-cracks can increase the permeability of concrete [9]. Also, when the concrete resists external loads, mechanical cracks tend to occur at the existing micro-cracks and propagate between the paste and coarse aggregate which can lead to the failure of the concrete. Therefore, the exclusion of coarse aggregate is necessary to improve the durability and strength of reactive powder concretes [10]. In a mixed design, the largest granular particle is Calcined Bauxite with an average diameter of 3 to 7 mm, the second largest particle is cement with roughly 15 µm average diameters, and he obtained 141.77 MPa compressive strength for a cylinder shape and 8”x4” size [11].

Sobuz et al. [11’] reported that the compressive strengths of UHPC through 130-160 MPa can be produced using graded aggregates without the requirement for complex mixing or curing regimes. It has been shown that the fineness modulus (FM) of aggregates and the superplasticizer content strongly influence the compressive strength. Table 1 shows the mix proportion that gained 162 MPa after 56 days using sulfate-resistant cement, washed river sand having an FM of 2.34, and a third-generation high range-water reducer with an added retarder.

Table 1: Powder concrete mix proportion

Cement	Sand	Silica Fume	Steel fiber	W/C ratio	Super Plasticizer/C	Total water/C
1	1	0.266	0.233	0.165	0.038	0.19

Currently, the studies indicate that there are many optimizations to spreading and producing Ultra-high-performance concrete. Muhammad A. Saleem et al [12] presented the developmental process of (UHPC), the most advanced form of concrete. The UHPC of mixes are prepared without using any specialized mixer or treatments. The results indicated that producing self-compacting UHPC with compressive strength ranging from 120 to 160 MPa, employing local materials. Additionally, the inclusion of steel fibers and the application of heat treatment remarkably enhanced compressive strength. While Mousavinezhad et al.[13] investigated replacing cement, SF, and fly ash in Ultra-High-Performance Concrete mixtures with ground granulated blast-furnace slag, metakaolin, and a pozzolan. It was found that 75, 100, and 40% of fly ash in the control mixture could be replaced with pumicite, metakaolin, and ground granulated blast-furnace slag, respectively, while still producing acceptable strengths. On the other hand, the flexural strengths were greater than 14.20 MPa for all mixtures, though UHPC mixtures had shrinkage strains no greater than 406 µ strain and “very low” susceptibility to chloride ion penetration. A recent study by El-Dessouky [14] showed the development of the UHPC. The method depends on to development of the mechanical properties of Ultra-High-Performance Concrete using locally available resources. The outcomes indicated that increasing the fibre volume will reduce the workability of UHPC. Additionally, I have an Unnoticeable improvement in compressive strength, though it was a significant improvement in splitting tensile and flexural strength.

This work is focused on the production of the Ultra-High Strength Concrete mix using local aggregates, and mineral and chemical admixtures. In addition to studying the effect of silica fume, superplasticizer, and size effect.

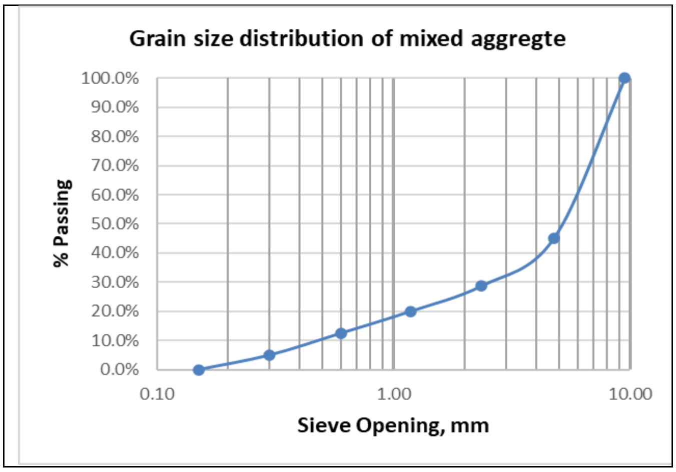
Material specifications

The properties of the materials involved in the three trial mixes are considered the same for every type and independent of the sample shape and size. Dolomite crushed stone is used as coarse aggregate with M.N.S of 9.5 mm and siliceous sand is used as fine aggregate with M.N.S of 4.75 mm and returned on sieve 150 µm; both of the coarse and fine aggregates were well washed and dried in the oven for all used aggregate for specimens’ fabrication. Figure 1 shows the grain size distribution of the powder concrete mixed aggregate for the three trials. Ordinary Portland cement type I was used in all mixes. Silica fume in powder form contains extremely fine (0.1 µm) latently reactive silicon dioxide, and its specific gravity is 2.2. Sikament 163 M is used as high-range water-reducing concrete. Admixture is used in the first and second trial mixes, which are substituted in the third trial by a Basf product, namely Master Glenium RMC 315, which is a unique third-generation superplasticizer based on modified Polycarboxylic ether. For both the coarse and fine aggregate, the specific gravity tests of the Saturated Surface Dry (SSD) state were carried out on the specimens as per ASTM 127 and ASTM 128 standards and found to be 2.655 and 2.595, respectively, and the percentage of absorption for both of them were 3% and 1% respectively.

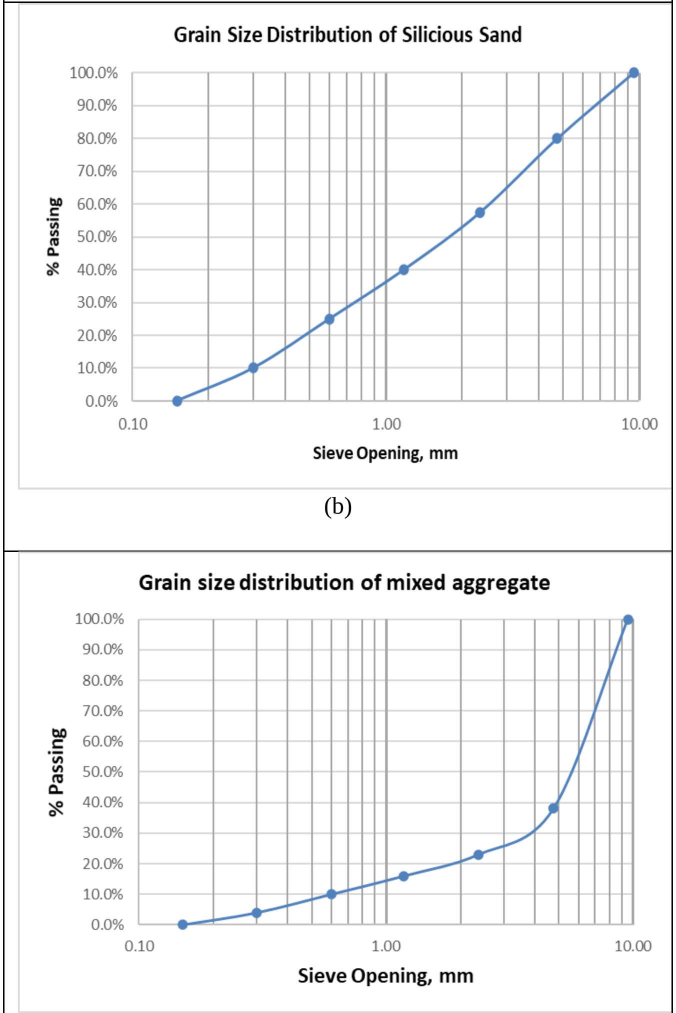
Table 2 represents the aggregate's grain size distribution for trials 1, 2, and 3. The fineness modulus was 4.89, 3.88, and 5.09, respectively. Figure 1 shows the grain size distribution curves of the powder concrete mixed aggregate a and c; curve b shows that of siliceous sand.

Table 2: Grain size distribution of the aggregate for trial 1, trial 2 and trial 3

Sieve Opening mm	% Passing		
	Trial 1	Trial 2	Trial 3
9.5	100	100	100
4.75	45	80	38
2.36	28.8	58	23
1.18	20	40	16
0.6	12.5	25	10
0.3	5	10	4
0.15	0	0	0



(a)



(b)

(c)

Fig. 1: Curves a, b and c depict the grain size distribution of mixed aggregate for first, second and third trial mixes respectively.

Experimental procedures

In this study, three trial mixes and their proportions shown in Table 3, were performed to experimentally reach the compressive strength of UHSC using the conventional materials. In the first trial mix, six cubes of 150 mm edge length were fabricated using Sikament 163M as a range water reducer (HRWR) to improve the workability that made the mix of this trial sloppy; three of the specimens were tested after 7 days. additional, the rest were tested after 28 days. In the second trial, the coarse aggregate is excluded, and a reduction in water content as well as the chemical admixture trying to make the mix stiffer. Six cubes of 150 mm edge length were fabricated and tested after 7 and 28 days. While, the third trial mix, the chemical admixture Sikament 163M is substituted by Master Glenium RMC 315, and a significant reduction in silica fume content from 0.25 in the first and second trial mixes down to 0.136 of the cement contents, six cubes of 100 mm edge length were fabricated and tested after 7 and 28 days. The third trial mix achieved higher results in the compression strength test compared to the two previous mixes, so the next mix of the series 4 was fabricated using the same mix proportion as the third trial mix to examine the size and shape effects on the compression strength test after 28 days of the specimens. Table 4, shows the sizes and shapes of specimens of the test program. It should be noted that the free water in the HRWR did not add to the water content in the mixes.

Table 3: Mix proportion by weight for the three trial mixes

Trial	Cement	SF	Crushed Stone	Fine Aggregate	Super Plasticizer	W/B
1st	1	0.25	0.55	0.45	0.094	0.192
2nd	1	0.25	0	1.116	0.084	0.135
3rd	1	0.136	1.09	0.733	0.057	0.225

Table 4: Test program

Trial	Cubes (edge length) cm			Cylinders (Ø x height) cm			Num. of specimen
	7x7 x7	10x10 x10	15x15x 15	10x 15	10x 20	15x 30	
1st			√				6 cubes
2nd			√				6 cubes
3rd		√					6 cubes
Series 4	√	√	√	√	√	√	3 specimens for each size

Results and discussion

Table 5 shows the results of the compressive strength test.

Table 5: The results of compressive strength test of specimens.

Trial/ Series	Shape	Age (days)	Dim. (cm)	Average Fc (MPa)	Chemical Admixture
Trial #1	Cubes	7	15	46	Sikament 163M
	Cubes	28	15	65	
Trial #2	Cubes	7	15	49	
	Cubes	28	15	56	
Trial #3	Cubes	7	10	80	Master Glenium RMC 315
	Cubes	28	10	107	
Series #4	Cubes	28	7	41	
	Cubes	28	10	40	
	Cubes	28	15	65	
	Cylinder	28	Ø10x15	37	
	Cylinder	28	Ø10x20	35	
	Cylinder	28	Ø15x30	38	

1. Superplasticizer dosage

The content of HRWR in the powder concretes mix is highly dependent on the active solids existing in the HRWR liquid to disperse molecules, this is the reason for not adhere the dosage of HRWR advised by the manufacturer [15].

2. The effect of silica fume

2.1. Silica fume content

Hydration proceeds in pastes with SF, about both Ca(OH)2 and non-evaporable water contents, SF interacts with calcium hydroxide (CH) and produces calcium silicate hydrate (CSH). The increase in the strength can be explained by the Calcium-Silica-Hydrate (CSH) gel formed by the hydration of dicalcium silicate (C2S) and tricalcium silicate (C3S). Referring to Figure 2, it is noticed that the first and second trials have a silica fume content equal to 25 % of the cement content. Using the same type of HRWR (Sikament 163M), these two factors have an obvious impact in producing the low compressive strength compared to the third trial mix that contains silica fume equals 13.6 %. This result agrees with [10] that at the constant w/b ratio equals 0.2, the ultimate compressive strength is achieved at SF content between 10% and 15 % all over the age of specimens from 1 to 90 days compared to mixes that have other contents of the SF.

2.2. Silica fume and fine aggregate

According to [10], "when the binder contains silica fume, using fine sand does not increase compressive strength. This may be the reason that the second trial has the least compressive strength after 28 days compared to the first. Also, the third trial contains dolomite crushed stone as coarse aggregate.

2.3. Silica fume and Superplasticizer

Despite that, the third trial had the least cement and silica content compared to the first and second trials, but it achieved the highest compressive strength. Because of changing the HRWR from Sikament 163M to Master Glenium RMC 315 which has the polycarboxylate ether base.

3. Size effect

Figure 3, depicts the obvious difference in results between the compressive strength of the 150 mm cube shape and both the 70 and 100mm cubes. Whereas the difference is not significant between the three sizes of the cylinder shape. Also, in general the Fc of the cube shape is higher than that of the cylinder shape especially the 150 mm cube size. The Fc of cylinder 100x150 is higher than that of cylinder 100x200 due to the variation of the slenderness ratio. The result of cylinder 150 x 300 mm is 1.08 times for that of cylinder 100 x 200 mm which is near to the rate of 1.06 between both cylinder sizes in [16] and also the wall effect stated in [8] agrees with the result of the research.

Referring to Figure 4, despite using the same mix proportion for both trial 3 and series 4 specimens, a considerable difference between them is noted. This happened due to the retreat of the effectiveness of both the silica fume powder and the chemical admixture used in specimens of series 4.

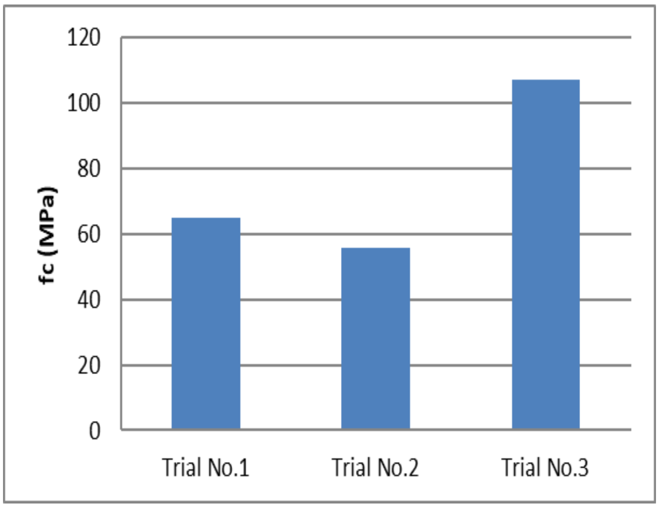


Fig. 2: Effect of high silica fume content on Fc of first and second trials (0.25) compared to the third trial (0.136).

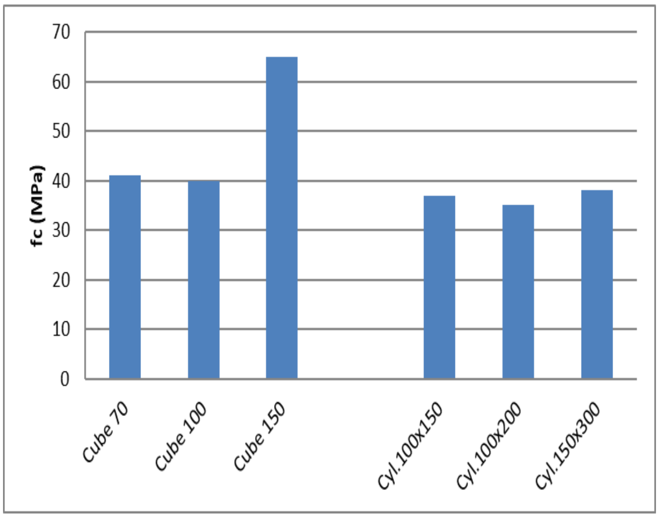


Fig. 3: Compressive strength of specimens of series 4 after 28 days.

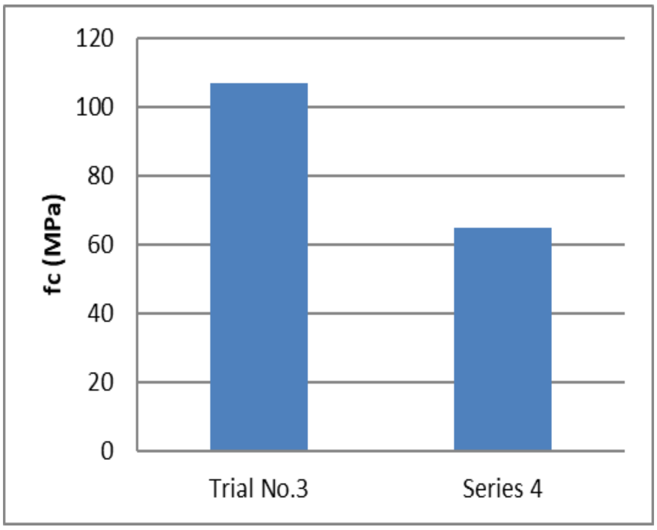


Fig. 4: Fc of cubes 150 mm for trial 3 and Series 4 using the same mix proportion.

Curing regime effect

From Figure 5, a significant increase in compressive strength test was observed between results of both 7 and 28-days tests of 150 mm cubes of trial No.3. Which ensures the efficiency of the normal curing in clear water, the increase is about 33 %.

Mode of failure

As shown in Figure 6, the failure patterns are satisfactory for the cube and the cylinder; all cracks of failure are Trans granular, showing that the strength of the mortar exceeded the strength of the grains of the coarse aggregate.

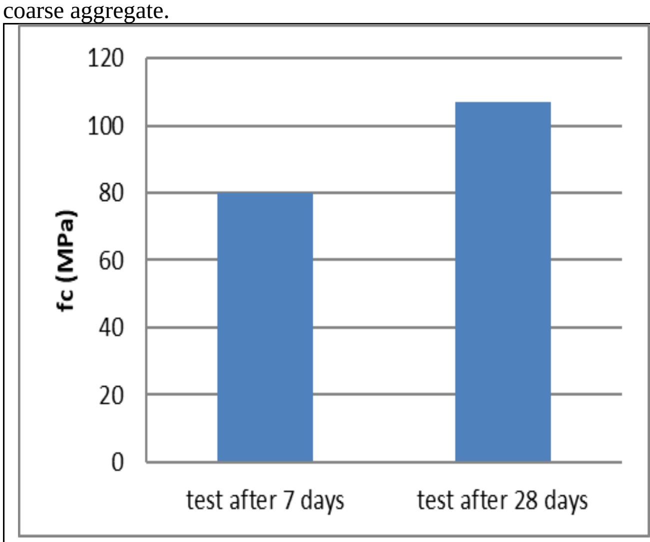


Fig. 5: Results of 7 and 28 days of cubes 150 mm of trial No. 3.

(a)

(b)

Fig. 6: The failure mode (a) of 150 mm edge length cube and (b) Ø 150 x 300 mm cylindrical shape.

Conclusions

1. Adding SF content of the powder concrete mix up to 15 % get higher compressive strength than higher SF content.
2. High-range water reducer based on polycarboxylates ether obtains better results than that of naphthalene sulfonate, melamine sulfonate lignosulfonate-based, or any combination between them.
3. Using SF in a mix contains siliceous sand only as aggregate get low compressive strength compared with powder concrete mixes contains coarse aggregate.
4. A slight difference Fc test after 28 days was noted between both 70 and 100 mm edge length cubes, whereas those of 150 mm cubes show a higher compressive strength, while the three sizes of the cylindrical shape have minimal differences between their results do not exceed 9%.
5. The rate of the active solids content in the HRWR liquid highly controls the HRWR content in the powder concretes mix.

References

[1] Fiber Structural Concrete, Textbook on behavior design and performance. CEB-FIP: France, 2009, 1(52).

[2] Corbu, O.-C., Popa, M., Zagon, R., (2013), Achieving mixtures of ultra-high-performance concrete., Construct,11, 1, 40-45.

[3] Shi, C., Wu, Z., Xiao, J., Wang, D., Huang, Z., Fang, Z. (2015), A review on ultra high performance concrete: Part I. Raw materials and mixture design., Construction and Building Materials, 101, 741-751. DOI: https://doi.org/10.1016/

[4] Nallathambi, P., Karihaloo, B. L., Heaton, B. S., (1984), Effect of specimen and crack sizes, water/ cement ratio and coarse aggregate texture upon fracture toughness of concrete., Mag. of Concr. Res., 36(129), 227-236.

[5] Foy, C., Pigeon, M., Banthia, N., (1988), Freeze-thaw durability and deicer salt scaling resistance of a 0,25 water-cement ratio concrete., Cement and Concrete Research., 18(4), 604-614. DOI: 10.1016/0008-8846(88)90053-1

[6] Yi, S.-T., Yang, E.-I., Choi, J.-C., (2006), Effect of specimen sizes, specimen shapes, and placement directions on compressive strength of concrete., Nuclear Engineering and Design, 236(2), 115-127. DOI: 10.1016/j.nucengdes.2005.08.004

[7] Riedel, P., Leutbecher, T., (2017), Effect of specimen size on the compressive strength of ultra-high-performance concrete., AFGC-ACI-fib-RILEM Int., Montpellier, France. October 2-4, 251-260.

[8] Badawy, A.A.M., Sallam, H. E.M., Sellem, M.H., (2007), Effect of coarse aggregate type and specimen geometry on mechanical properties of NSC and HSC., Al-Azhar University Engineering Journal, JAUES, 2(3), Cairo, 200-209.

[9] Magureanu, C., Sosa, I., Negrutiu, C., and Heghes, B., (2012), Mechanical Properties and Durability of Ultra-High-Performance Concrete., ACI Mater. J., 109(2), 177-184. DOI: 10.14359/51683704

[10] Alsalman, A., Dang, C. N., Hale, W. M., (2017), Development of ultra-high performance concrete with locally available materials., Construction and Building Materials, 133(15), 135-145. DOI: 10.1016/j.conbuildmat.2016.12.040

[11] Gheitanbaf, E. H., Fracture toughness of ultra-high performance concrete, B. SC. in civil engineering, University of Tehran, Iran, July, 2011.

[12] Saleem, A. M., (2024), Development and characterization of non-proprietary ultra-high-performance concrete, Heliyon,10 (2), 1-16. DOI: 10.1016/j.heliyon.2024.e24260

[13] Mousavinezhad, S Gonzales, G.J.,(2023), Toledo,W.K.; Garcia, J.M.; Newtson, C.M.; Allena, S. A Comprehensive Study on Non-Proprietary Ultra-High-Performance Concrete Containing Supplementary Cementitious Materials, Materials, 16(7), 1-19. DOI: 10.3390/ma16072622
EL-Desouky, M., (2024), Development and Improving of Ultra- High-Performance concrete Egypt, International Peer Reviewed Journal, 10(1), 1160-1169.

[14] Aïtcin, P.- C., High Performance Concrete, CRC Press, London, , July, 1998.

[15] Tokyay., M., Ozdemir., M , (1997), Specimen shape and size effect on the compressive strength of higher strength concrete, Cement and Concrete Research, 27(8) , 1281-1289.