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Ultra-high-performance concrete: Impacts of steel fibre shape and content on flowability, compressive strength and modulus of rupture

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ABSTRACT

The impact of three-shaped steel fibres (straight, hooked end, and corrugated) with varying steel fibre (SF) contents (0.75 %, 1.5 %, and 2.5 % by volume fraction) on the fresh and mechanical characteristics of ultra-high-performance concrete was investigated in this investigation. The characteristics concerned included flowability, compressive strength, and modulus of rupture. The findings showed that using deformed fibres and increasing the fibre volume could gradually reduce the flowability of ultra-high-performance concrete. It also had a substantial impact on the compressive strength and modulus of rupture of ultra-high-performance concrete. At 28-d, its compressive strength and modulus of rupture were greater than 155 and 37 MPa, respectively, with the introduction of 2.5 % straight SFs. Moreover, the compressive strength increased by 50 % and 65 % for concrete comprising 2.5 % hooked end fibre and corrugated fibre, respectively, when compared to concrete with the same volume of straight fibre.

1. Introduction

Ultra-high-performance concrete is a material having a high cement-based material content, fine aggregate, fibre volume, superplasticizer, and low water to cement-based material ratio. It possesses strong strength, durability, and toughness [1–4]. The addition of fibre can provide ultra-high-performance concrete with strain-hardening behaviour under tension while also converting brittle failure to ductile failure [5,6]. Several investigations on composition optimization, behaviour improvement, energy reduction, and cost reduction have been undertaken [7,8]. Until recently, Kassel University in University has hosted three international symposiums on ultra-high-performance concrete [9–12].

Several variables impact the modulus of rupture characteristics of ultra-high-performance concrete, such as fibre volume, fibre distribution, fibre mixing, fibre and sample size, and placement procedures, among others [13,14]. "Kang, Lee, Kim and Kim [15] investigated the impacts of fibre distribution on the modulus of rupture of SF-reinforced ultra-high strength concrete placed in two various directions and discovered that the ultimate modulus of ruptures and initial cracking of ultra-high-performance concrete placed

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parallel to the longitudinal direction of the mold were 60% and 5.6% higher, respectively than those placed transversely. Dawood and Ramli [16] studied the mechanical characteristics of high strength flowing concrete using 1.50% hybrid SF, synthetic, and palm fibres. It was discovered that as the amount of hybrid fibres grew, so did the initial crack strength and post-crack strength [17–20]. According to Kim, Park, Ryu and Koh [21], the deflection capacity, modulus of rupture, and energy absorption capacity of ultra-high-performance concrete reinforced with various macro fibres improved differently as the blended quantity of microfibre raised [22–24]. By pouring three circular panels in three various ways, Barnett, Lataste, Parry, Millard and Soutsos [25] investigated the impacts of casting procedures on the modulus of rupture. Panels poured from the center were determined to be the strongest [26–28]. Fibre mixing is a viable strategy for improving the modulus of rupture behaviour of ultra-high-performance fibre-reinforced concrete (UHPFRC), allowing macrofibres and microfibres to play various roles" [29–31].

The goal of this study is to consider the impacts of varied fibre volumes (0, 0.75%, 1.5%, and 2.5%) with three various shaped fibres (straight fibre, hooked end fibre, and corrugated fibre) on the flowability, compressive strength, and modulus of rupture of ultra-high-performance concrete.

2. Investigation significance

Due to the advantages and challenges specific to ultra-high-performance concrete, "additional studies are warranted. This paper aims to improve the understanding of ultra-high-performance concrete by investigating the impacts of steel fibre shape and volume on flowability and compressive strength and modulus of rupture."

3. Experimental program

3.1. Raw materials

The cement used was ordinary Portland cement (type I). The physiochemical composition of cement-based materials is summarized in Tables 1 and 2. Microsilica was employed, with an average particle size of 0.15 μm. Three SFs with a tensile strength of around 270 GPa were used: straight fibre, hooked end fibre, and corrugated fibre. Table 2 summarizes the characteristics of steel fibre. Natural sand with a maximum particle size of 2.36 mm, as shown in Fig. 1, was employed. Moreover, a polycarboxylate-based superplasticizer was employed.

3.2. Mixture proportions

According to Shi, Wang, Wu and Wu [32], "a mixing percentage of ultra-high-performance concrete with water to cement-based materials ratio of 0.20 was utilized, as indicated in Table 3. The superplasticizer dose was set at 1.7% of the cement-based materials' mass. SF concentrations of 0.75%, 1.5%, and 2.5% by volume of concrete were utilized. As illustrated in Table 3, ultra-high-performance concrete combinations comprising straight fibre, hooked end fibre, and corrugated fibre were labeled M1, M2, and M3, respectively."

3.3. Mix procedure and sample preparation

For the mixture process, "dry powders such as cement, microsilica, and natural sand were initially combined at high speed for 2 min. The water and superplasticizer were then added and combined for around 7 min on low speed. Following that, SFs were introduced and mixed for another 5 min until the mixes were evenly dispersed. When the ultra-high-performance concrete mixes were finished, they were cast in two layers into 40 × 40 × 160 mm^3 molds and vibrated 60 times at each layer to consolidate the mixes. Molded specimens were maintained in a chamber at 25 °C for 24 h. They were wrapped in plastic sheets to keep moisture out before demolding. Following that, specimens were cured in saturated lime water at 25 °C for 3, 7, 28, and 90-d."

3.4. Experimental methods

3.4.1. Flowability

The flowability of all ultra-high-performance concrete mixes was determined using ASTM C-1437 [33]. The mixes were poured into a small cone mold, which was then put on an automated jolting table. The mold was vertically raised and jolted 25 times. The mean value of two diameters perpendicular to each other was then calculated.

Table 1
Physical characteristics of cement-based materials.

"Physical Characteristics	Specific area (cm^2/gm)	Mean grain size (μm)	Colour	Initial setting (min)	Final setting (min)	Density (g/cm^3)	Specific gravity
Cement	3255	22.6	Dark Grey	48	365	3.14	2.22
Microsilica	150000-300000	0.15	Light to Dark Grey	–	–	2.23	3.12"

Table 2
Chemical compositions of cement-based materials.

"Compositions (%)	CaO	Al_2O_3	SiO_2	MgO	Fe_2O_3	NM1–2 O	K_2O	SO_3	LOI
Cement	63.63	5.05	20.27	4.58	3.18	0.09	0.53	2.2	3.14
Microsilica	0.8	1.13	86	0.9	1.48	0.9	1.055	–	< 7"

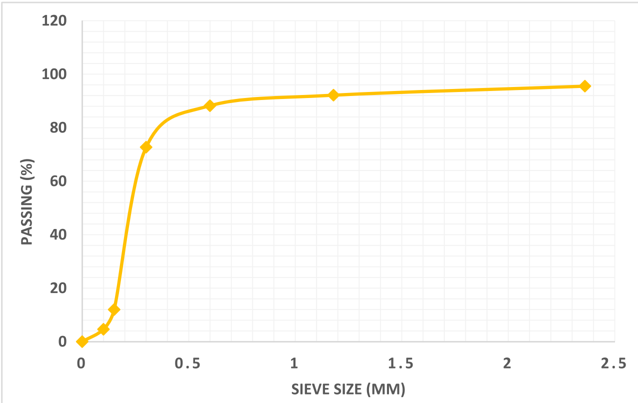

Fig. 1. Natural sand grain size distribution.

Table 3
Mixture proportions of ultra-high-performance concrete.

No.	SF content by volume (%)	SF (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	microsilica (kg/m^3)	Water (kg/m^3)	Super-plasticizer (kg/m^3)
Ref.	0	0	790	1062	285	174	22.3
M1–1	0.5	69	811	1050	281	171	22.1
M1–2	1.5	148	802	1042	276	169	21.8
M1–3	2.5	226	792	1035	265	167	21.6
M2–1	0.5	69	811	1050	281	171	22.1
M2–2	1.5	148	802	1042	276	169	21.8
M2–3	2.5	226	792	1035	265	167	21.6
M3–1	0.5	69	811	1050	281	171	22.1
M3–2	1.5	148	802	1042	276	169	21.8
M3–3	2.5	226	792	1035	265	167	21.6

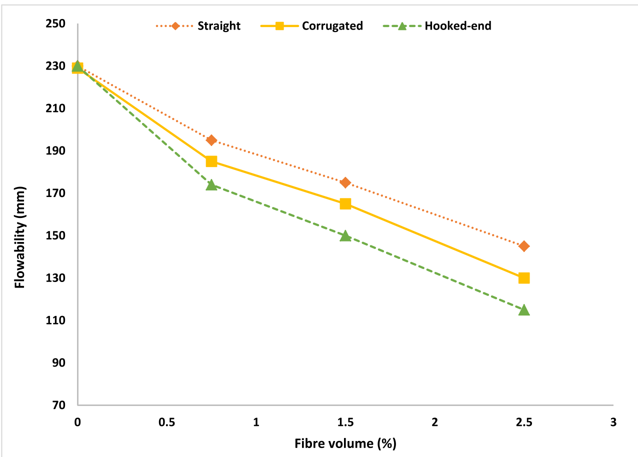

Fig. 2. Impacts of SF volume and shape on the flowability of fresh ultra-high-performance concrete mixes.

3.4.2. Modulus of rupture strength testing

The impacts of SF volume and shape on the modulus of rupture indices of ultra-high-performance concrete were investigated using three-point modulus of rupture testing with displacement reference. A Universal testing machine with a load cell of 25000 KN was utilized. It was programmed to load at a rate of 0.3 mm/min. As tested findings, the averages of three samples from each batch were presented.

3.4.3. Compressive strength (CS) testing

Nine cubic specimens with dimensions of 50 mm were utilized to calculate CS. 3 KN/s was the loading rate. As tested findings, the averages of specimens made from each batch were presented.

4. Findings and discussion

4.1. Flowability

Fig. 2 depicts the impacts of SF concentration and shape on the flowability of fresh ultra-high-performance concrete mixes. The reference batch (Ref.) had a flowability of 230 mm. With the addition of 0.75 %, 1.5 %, and 2.5 % straight SFs, the flowability steadily reduced by 11 %, 21 %, and 32 %, respectively. This might be attributed to an increase in the specific surface area caused by an increase in fibre volume [2,5]. Furthermore, the SFs were randomly dispersed in the matrix and served as a skeleton, ultimately preventing the flow of fresh concrete [6,10,34,35].

The flowability was also impacted by the form of the fibre. "When compared to straight and corrugated fibres, ultra-high-performance concrete samples with hooked ends showed the lowest flowability. The flowability of mixes comprising 0.75 %, 1.5 %, and 2.5 % hooked end SFs was decreased by 15 %, 29 %, and 43 %, respectively, when compared to those comprising the same volume of straight fibres. It decreased by 14 %, 28 %, and 32 % for combinations comprising 0.75 %, 1.5 %, and 2.5 % corrugated fibres, respectively. This was mostly due to the fact that deformed fibres might increase the friction between aggregates and fibres, increasing coherence with the matrix and hence reducing flowability. Furthermore, changes in fibre form result in a strengthening impact among fibres, making them more likely to bundle with one another [13,14]."

4.2. Compressive strength (CS) and modulus of rupture

4.2.1. Impacts of SF volume

Figs. 3 and 4 depict the change in CS and modulus of rupture of ultra-high-performance concrete with varying straight fibre volumes after 3, 7, 28, and 90-d. It can be shown that with increasing age and fibre volume, both CS and modulus of rupture rose steadily. Moreover, 2.5 % straight SFs dramatically boosted 90-d CS and modulus of rupture exceeding 165 and 42 MPa, respectively. As previously stated, greater SF concentration may reduce the average spacing between fibres, causing more fibres to bear stress and lead to multi-cracks [36–40]. Meanwhile, as the fibre volume raised, the tension between the matrix and the fibre decreased, delaying the development and propagation of fractures and therefore increasing strength [8,41].

As seen in Figs. 3 and 4, the degree of strength gain slows with age. Particularly, the modulus of ruptures at 28 and 90-d were almost identical. This was primarily due to the comparatively thick structure of ultra-high-performance concrete combined with unusually low water to cement-based materials ratio, which did not provide enough free water for cement hydration at later ages [2,10,42].

4.2.2. Impacts of SF shape

Figs. 5 and 6 show the impacts of fibre form on the CS and modulus of rupture of ultra-high-performance concrete with and without

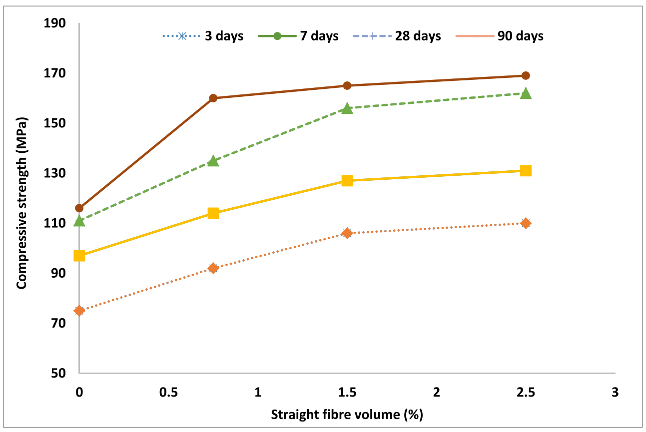

Fig. 3. Impacts of fibre volume on CS of Ultra-high-performance concrete.

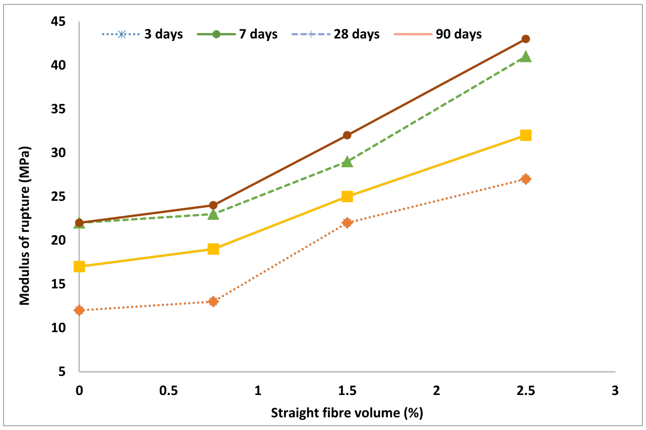

Fig. 4. Impacts of fibre volume on the modulus of rupture of ultra-high-performance concrete.

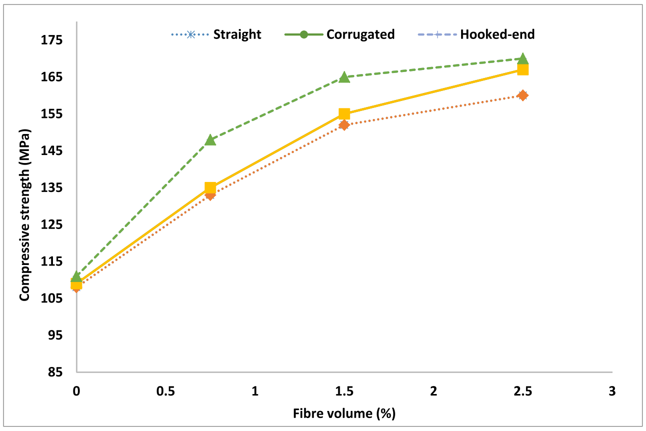

Fig. 5. Impacts of steel fibre volume and shape on CS of Ultra-high-performance concrete (28-d).

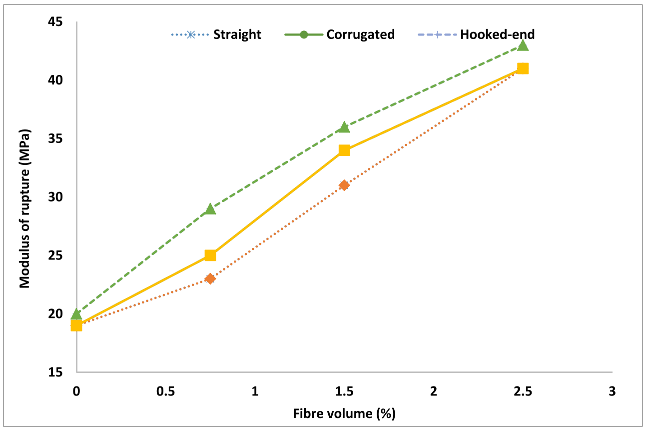

Fig. 6. Impacts of steel fibre volume and shape on the modulus of rupture of ultra-high-performance concrete (28-d).

SF after 28-d. The ultra-high-performance concrete with hooked end fibres had the greatest CS and modulus of ruptures, whereas the ultra-high-performance concrete with straight fibres had the lowest. At 28-d, the CS of the reference ultra-high-performance concrete sample was 111 MPa. When 0.75 %, 1.5 %, and 2.5 % straight SFs were added, it grew by 25 %, 46 %, and 51 %, respectively. The CS improved by 35 %, 52 %, and 64 % when 0.75 %, 1.5 %, and 2.5 % hooked end fibres were added, respectively. modulus of rupture strength followed the same pattern. This might be due to differences in bonding strength caused by fibre geometry [2,41,43,44]. The anchoring mechanical force connected with the fibre-end, chemical bond, and friction all contribute to the bonding strength at the fibre-matrix interface. It has been a concept that hooked end fibres produce greater mechanical interlock than other shaped fibres [6, 8].

5. Conclusions

The following conclusions can be derived from the study's findings:

1. The addition of SF significantly reduced the flowability of ultra-high-performance concrete. The flowability steadily reduced as the volume of fibre raised.
2. The incorporation of distorted fibres could also decrease flowability.
3. Compressive and modulus of rupture increased with fibre volume and age.
4. The compressive strength (CS) and modulus of ruptures of fibreless ultra-high-performance concrete samples were 111 MPa and 23 MPa after 90-d, respectively. With the addition of 2.5 % straight SFs, the equivalent values increased to 165 MPa and 42 MPa, respectively.

CRediT authorship contribution statement

Conception and design of study: M.H. Akeed, S. Qaidi; Acquisition of data: B.H. Abu Bakar: analysis and/or interpretation of data: B.A. Tayeh. Drafting the manuscript: M.H. Akeed, S. Qaidi; revising the manuscript critically for important intellectual content: B.A. Tayeh, B.H. Abu Bakar. Approval of the version of the manuscript to be published: Bassam A. Tayeha, Mahmoud H. Akeedb, Shaker Qaidic,d, B.H. Abu Bakar.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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References

[1] F. Aslam, O. Zaid, F. Althoey, S.H. Alyami, S.M.A. Qaidi, J. de Prado Gil, R. Martínez-García, Evaluating the influence of fly ash and waste glass on the characteristics of coconut fibers reinforced concrete, Struct. Concr. (2022).
[2] Y.I.A. Aisheh, D.S. Atrushi, M.H. Akeed, S. Qaidi, B.A. Tayeh, Influence of steel fibers and microsilica on the mechanical properties of ultra-high-performance geopolymer concrete (UHP-GPC), Case Stud. Constr. Mater. 17 (2022), e01245.
[3] L. Gemi, E. Madenci, Y.O. Özkılıç, Experimental, analytical and numerical investigation of pultruded GFRP composite beams infilled with hybrid FRP reinforced concrete, Eng. Struct. 244 (2021), 112790.
[4] Y.O. Özkılıç, Ş. Yazman, C. Aksoylu, M.H. Arslan, L. Gemi, Numerical investigation of the parameters influencing the behavior of dapped end prefabricated concrete purlins with and without CFRP strengthening, Constr. Build. Mater. 275 (2021), 122173.
[5] B.A. Tayeh, M.H. Akeed, S. Qaidi, B.H.A. Bakar, Influence of microsilica and polypropylene fibers on the fresh and mechanical properties of ultra-high performance geopolymer concrete (UHP-GPC), Case Stud. Constr. Mater. 17 (2022), e01367.
[6] Y.I.A. Aisheh, D.S. Atrushi, M.H. Akeed, S. Qaidi, B.A. Tayeh, Influence of polypropylene and steel fibers on the mechanical properties of ultra-high-performance fiber-reinforced geopolymer concrete, Case Stud. Constr. Mater. 17 (2022), e01234.
[7] W. Emad, A.S. Mohammed, A. Bras, P.G. Asteris, R. Kurda, Z. Muhammed, A.M.T. Hassan, S.M.A. Qaidi, P. Sihag, Metamodel techniques to estimate the compressive strength of UHPFRC using various mix proportions and a high range of curing temperatures, Constr. Build. Mater. 349 (2022), 128737.
[8] M.H. Akeed, S. Qaidi, H.U. Ahmed, W. Emad, R.H. Faraj, A.S. Mohammed, B.A. Tayeh, A.R.G. Azevedo, Ultra-high-performance fiber-reinforced concrete. Part III: fresh and hardened properties, Case Stud. Constr. Mater. 17 (2022), e01265.
[9] M.H. Akeed, S. Qaidi, H.U. Ahmed, R.H. Faraj, A.S. Mohammed, W. Emad, B.A. Tayeh, A.R.G. Azevedo, Ultra-high-performance fiber-reinforced concrete. Part IV: durability properties, cost assessment, applications, and challenges, Case Stud. Constr. Mater. 17 (2022), e01271.
[10] S. Qaidi, Ultra-High-Performance Fiber-Reinforced Concrete: Fresh Properties, Preprints (2022).
[11] E. Najaf, H. Abbasi, Using recycled concrete powder, waste glass powder, and plastic powder to improve the mechanical properties of compacted concrete: cement elimination approach, Adv. Civ. Eng. 2022 (2022).
[12] E. Najaf, M. Orouji, S.M. Zahrai, Improving nonlinear behavior and tensile and compressive strengths of sustainable lightweight concrete using waste glass powder, nanosilica, and recycled polypropylene fiber, Nonlinear Eng. 11 (1) (2022) 58–70.
[13] M.H. Akeed, S. Qaidi, H.U. Ahmed, R.H. Faraj, A.S. Mohammed, W. Emad, B.A. Tayeh, A.R.G. Azevedo, Ultra-high-performance fiber-reinforced concrete. Part I: developments, principles, raw materials, Case Stud. Constr. Mater. 17 (2022), e01290.
[14] M.H. Akeed, S. Qaidi, H.U. Ahmed, R.H. Faraj, A.S. Mohammed, W. Emad, B.A. Tayeh, A.R.G. Azevedo, Ultra-high-performance fiber-reinforced concrete. Part II: Hydration and microstructure, Case Stud. Constr. Mater. 17 (2022), e01289.

[15] S.T. Kang, B.Y. Lee, J.-K. Kim, Y.Y. Kim, The effect of fibre distribution characteristics on the flexural strength of steel fibre-reinforced ultra high strength concrete, Constr. Build. Mater. 25 (5) (2011) 2450–2457.
[16] E.T. Dawood, M. Ramli, Mechanical properties of high strength flowing concrete with hybrid fibers, Constr. Build. Mater. 28 (1) (2012) 193–200.
[17] C. Aksoylu, Ş. Yazman, Y.O. Özkılıç, L. Gemi, M.H. Arslan, Experimental analysis of reinforced concrete shear deficient beams with circular web openings strengthened by CFRP composite, Compos. Struct. 249 (2020), 112561.
[18] L. Gemi, C. Aksoylu, Ş. Yazman, Y.O. Özkılıç, M.H. Arslan, Experimental investigation of shear capacity and damage analysis of thinned end prefabricated concrete purlins strengthened by CFRP composite, Compos. Struct. 229 (2019), 111399.
[19] M. Orouji, S.M. Zahrai, E. Najaf, Effect of Glass Powder & Polypropylene Fibers on Compressive and Flexural Strengths, Toughness and Ductility of Concrete: An Environmental Approach. Structures, Elsevier, 2021, pp. 4616–4628.
[20] E. Najaf, H. Abbasi, S.M. Zahrai, Effect of waste glass powder, microsilica and polypropylene fibers on ductility, flexural and impact strengths of lightweight concrete, Int. J. Struct. Integr. (2022).
[21] D.J. Kim, S.H. Park, G.S. Ryu, K.T. Koh, Comparative flexural behavior of hybrid ultra high performance fiber reinforced concrete with different macro fibers, Constr. Build. Mater. 25 (11) (2011) 4144–4155.
[22] A.M. Zeyad, H.M. Magbool, M. Amran, M. Mijarsh, A. Almalki, Performance of high-strength green concrete under the influence of curing methods, volcanic pumice dust, and hot weather, Arch. Civ. Mech. Eng. 22 (3) (2022) 1–26.
[23] I.Y. Hakeem, M. Amin, A.M. Zeyad, B.A. Tayeh, A.M. Maglad, I.S. Agwa, Effects of nano sized sesame stalk and rice straw ashes on high-strength concrete properties, J. Clean. Prod. 370 (2022), 133542.
[24] A.M. Zeyad, I.Y. Hakeem, M. Amin, B.A. Tayeh, I.S. Agwa, Effect of aggregate and fibre types on ultra-high-performance concrete designed for radiation shielding, J. Build. Eng. 58 (2022), 104960.
[25] S.J. Barnett, J.-F. Lataste, T. Parry, S.G. Millard, M.N. Soutsos, Assessment of fibre orientation in ultra high performance fibre reinforced concrete and its effect on flexural strength, Mater. Struct. 43 (7) (2010) 1009–1023.
[26] I.S. Agwa, A.M. Zeyad, B.A. Tayeh, M. Amin, Effect of different burning degrees of sugarcane leaf ash on the properties of ultrahigh-strength concrete, J. Build. Eng. (2022), 104773.
[27] M. Amin, I.Y. Hakeem, A.M. Zeyad, B.A. Tayeh, A.M. Maglad, I.S. Agwa, Influence of recycled aggregates and carbon nanofibres on properties of ultra-high-performance concrete under elevated temperatures, Case Stud. Constr. Mater. 16 (2022), e01063.
[28] M. Amin, A.M. Zeyad, B.A. Tayeh, I.S. Agwa, Effect of ferrosilicon and silica fume on mechanical, durability, and microstructure characteristics of ultra high-performance concrete, Constr. Build. Mater. 320 (2022), 126233.
[29] E. Madenci, Y.O. Özkılıç, L. Gemi, Buckling and free vibration analyses of pultruded GFRP laminated composites: Experimental, numerical and analytical investigations, Compos. Struct. 254 (2020), 112806.
[30] E. Madenci, Y.O. Özkılıç, L. Gemi, Experimental and theoretical investigation on flexure performance of pultruded GFRP composite beams with damage analyses, Compos. Struct. 242 (2020), 112162.
[31] W. Adil, F.U. Rahman, G.M. Abdullah, B.A. Tayeh, A.M. Zeyad, Effective utilization of textile industry waste-derived and heat-treated pumice powder in cement mortar, Constr. Build. Mater. 351 (2022), 128966.
[32] C. Shi, D. Wang, L. Wu, Z. Wu, The hydration and microstructure of ultra high-strength concrete with cement–silica fume–slag binder, Cem. Concr. Compos. 61 (2015) 44–52.
[33] C. ASTM Standard test method for flow of hydraulic cement mortar C1437 2007.
[34] S. Qaidi, Ultra-High-Performance Fiber-Reinforced Concrete: Applications, Preprints (2022).
[35] S.M.A. Qaidi. Ultra-high-performance fiber-reinforced concrete: Hardened properties Univ. Duhok (UoD) 2022.
[36] Y.O. Özkılıç, C. Aksoylu, M.H. Arslan, Experimental and numerical investigations of steel fiber reinforced concrete dapped-end purlins, J. Build. Eng. 36 (2021), 102119.
[37] J. Ahmad, A. Majdi, A. Babeker Elhag, A.F. Deifalla, M. Soomro, H.F. Isleem, S. Qaidi, A. Step, Towards sustainable concrete with substitution of plastic waste in concrete: overview on mechanical, durability and microstructure analysis, Crystals 12 (7) (2022) 944.
[38] A.M. Maglad, O. Zaid, M.M. Arbili, G. Ascensão, A.A. Şerbănoiu, C.M. Grădinaru, R.M. García, S.M.A. Qaidi, F. Althoey, J. de Prado-Gil, A study on the properties of geopolymer concrete modified with nano graphene oxide, Buildings 12 (8) (2022) 1066.
[39] S.M.A. Qaidi, B.A. Tayeh, H.F. Isleem, A.R.G. de Azevedo, H.U. Ahmed, W. Emad, Sustainable utilization of red mud waste (bauxite residue) and slag for the production of geopolymer composites: a review, Case Stud. Constr. Mater. 16 (2022), e00994.
[40] S.M.A. Qaidi, D. Sulaiman Atrushi, A.S. Mohammed, H. Unis Ahmed, R.H. Faraj, W. Emad, B.A. Tayeh, H. Mohammed Najm, Ultra-high-performance geopolymer concrete: a review, Constr. Build. Mater. 346 (2022), 128495.
[41] M.H. Akeed, S. Qaidi, H.U. Ahmed, R.H. Faraj, S.S. Majeed, A.S. Mohammed, W. Emad, B.A. Tayeh, A.R.G. Azevedo, Ultra-high-performance fiber-reinforced concrete. Part V: mixture design, preparation, mixing, casting, and curing, Case Stud. Constr. Mater. 17 (2022), e01363.
[42] S.M.A. Qaidi. Ultra-high-performance fiber-reinforced concrete: Mixture design Univ. Duhok, Duhok 2022.
[43] R.H. Faraj, H.U. Ahmed, S. Rafiq, N.H. Sor, D.F. Ibrahim, S.M.A. Qaidi, Performance of self-compacting mortars modified with nanoparticles: a systematic review and modeling, Clean. Mater. 4 (2022), 100086.
[44] S.M.A. Qaidi, B.A. Tayeh, A.M. Zeyad, A.R.G. de Azevedo, H.U. Ahmed, W. Emad, Recycling of mine tailings for the geopolymers production: a systematic review, Case Stud. Constr. Mater. 16 (2022), e00933.