© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Optimisation of Ultra-High-Performance Concrete with Special Quarry Dust

Amir Mohammad Alizada[1], Ehsanullah Waseem[1], Sakhiah Abdul Kudus[1,2*], Zainorizuan Mohd Jaini[3,4]

[1]School of Civil Engineering, College of Engineering,
Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA

[2]Institute for Infrastructure Engineering and Sustainable Management,
Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA

[3]Structures Management Engineering Laboratory, Graduate School of Engineering,
Kyoto University, Kyoto 615-8540, JAPAN

[4]Structural Dynamic and Computational Engineering, Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA

*Corresponding Author

DOI: https://doi.org/ 10.30880/ijie.2023.15.02.002
Received 20 February 2023; Accepted 10 May 2023; Available online 13 June 2023

Abstract: The cement composition of concrete directly affects the CO_2 emissions to the environment. UHPC (Ultra High-Performance Concrete) is a new type of concrete rapidly gaining popularity in the building industry due to its superior strength and endurance. In contrast to regular concrete, UHPC requires more than twice as much cement, making it more expensive and leaving a more significant carbon imprint. In this study, waste cement was substituted with 4%, 8%, and 12% special quarry dust from a manufacturer in Kuantan, Malaysia. Maximum compressive strength and quarry dust percentage are determined through experimentation and assessed in Design Expert Software. This investigation tested modified UHPC for strength, durability, and scanning electron microscope (SEM) appearance. Experiments show that substituting 21% quarry dust for cement yields the best outcomes. Since the particle size of quarry dust is finer than that of other matrices, it helps to reduce voids and boosts the UHPC's endurances. The quarry dust adds filler and a minor increase in viscosity to the UHPC, which is a better replacement for anhydrate cement in filler applications.

Keywords: Green UHPC, strength and durability, quarry dust, rapid chloride permeability test

1. Introduction

According to ACI 239, UHPC is a cementitious concrete material with a minimum defined compressive strength of greater than 100 MPa with certain durability, tensile ductility, and toughness requirements; fibre is typically applied to meet desired characteristics [1]. HPC is more compact and has fewer voids attributable to its dense matrix. Higher cement content (700 - 1000 kg/m^3), a low *w/c* ratio, and the incorporation of fine cementitious material contribute to UHPC's compact matrix. The pozzolanic improves with an increase in cement content and cementitious material. Nevertheless, because it has a significantly higher cement content, UHPC causes an increase in the amount of carbon dioxide emissions [2].

*Corresponding author: sakhiah@uitm.edu.my

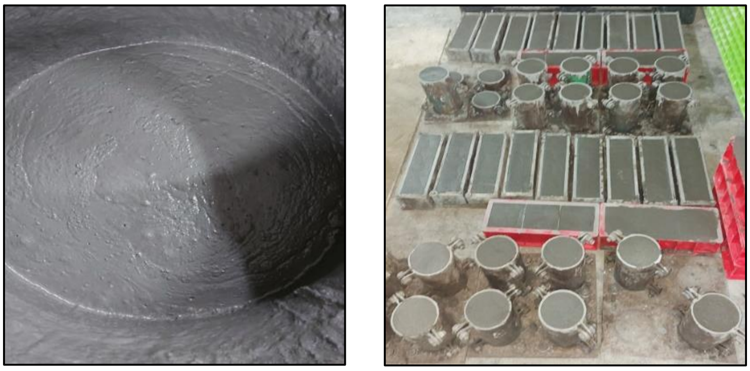
Consequently, it fails to fulfil the necessary criteria for environmental sustainability. In addition, approximately 40% of the cement used in UHPC is not hydrated, which forces the filler to be costly. The global application can be expanded by using recyclable materials to partially replace cement in UHPC while still preserving the material's strength and durability [3].

Various materials have been integrated into the UHPC matrix throughout the years to reduce its material cost and environmental impact while enhancing its workability. Fly ash (FA) has been shown to improve the reliability of concrete [4], [5], and its ultra-fine utilisation raises the resistivity, chloride migration coefficient, and alkali-silica reactivity (ASR) while lowering the carbonation resistance. Another study demonstrates that FA increases UHPC's splitting tensile strength, prolongs the material's life, and decreases thermal conductivity [5], [6]. The relative strength of UHPC increases when fly ash is employed to replace cement at a rate of up to 40% [7]. Furthermore, a study by Van Tuan [8] indicated that adding 20% by weight of rice husk ash (RHA) to UHPC boosts compressive strength by up to 15% . The binding quality of the substance is the contributing factor to this condition. Another extra cementitious ingredient, LP (Limestone Power), has been reported to generate compressive strengths similar to the control mix when applied as a binder substitute in UHPC at concentrations of up to 50% [9]. Another study substituted up to 25% dehydrated cementitious material from building waste for cement with similar results in compressive strength [10]. Besides, quarry stone powder is yet another type of recycled material used in UHPC to replace cement. A study by Yang et al. [11] stated that basalt and limestone quarry stone powder replace 22.2 - 44.4% of UHPC cement. Though the UHPC's autogenous shrinkage and dimensional stability enhanced owing to the substitution, the material's compressive strength dropped, particularly in the early curing days. Additionally, some studies have substituted a cheaper or recycled material for the UHPC's inert filler. Cathode ray tube waste glass was used in place of sand in one investigation, resulting in UHPC with reduced compressive and flexural strength [12]. Similar compressive strength was discovered in Yang et al. [11] research, where rock dust was substituted for up to 80% of the quartz sand. A study by Smarzewski [13] states that the optimal percentage of foundry waste sand to replace quartz sand is 5% to achieve comparable compressive and tensile strength levels. Despite their widespread use in UHPC, cementitious materials like fly ash and slag are experiencing quality control issues and undergoing production cuts due to international regulations on industrial waste. Therefore, the emphasis should be placed on cementitious material that is abundant and of consistent quality, such as powdered granite stone. This study used a by-product of quarry dust manufactured in Kuantan, Malaysia, by crushing granite slabs. The granite stone blocks are between 15 and 23 centimeters in size and are cut down to smaller sizes like 10mm, 15mm, and 19mm. The leftover quarry dust is often used as a premix or disposed of at a landfill. Through the use of compressive testing, tensile testing, flexural testing, water absorption testing, rapid chloride permeability testing (RCPT), carbonation testing, and scanning electron microscopy (SEM), this study seeks to determine the optimal percentage of processed quarry dust stone as partial cement replacement in the UHPC.

2. Methodology

The UHPC mix design in this study omits steel fibre to keep costs down, and a partial cement component is substituted with specialised quarry dust. This study used the following materials: fine river sand, ordinary Prortland cement (OPC), silica fume (SF), quarry dust (QD), superplasticizer, and water. To identify possible chemical elements that exist in quarry dust, silica fume, and cement the XRF (X-Ray Fluorescent Spectrometry) which is a chemical analysis of material, based on BS ISO 29581-2[14] were conducted. Proportions for the mix design were established by Wille et al. [15]. The quarry dust powder applied is distinct from previous studies since it was subjected to heating before being used [15]. For better durability and strength of concrete the packing of its granular raw materials is highly important [16]. Thus, SEM experiment were conducted to determine average particle size of silica fume, cement, and quarry dust, and sieve analysis were performed to find the particle size distribution of sand used in this experiment. A superplasticizer is necessary to keep the fresh concrete fluid. The Master Glenium ACE 8538 produced by Master Builder Solution (Malaysia) Sdn Bhd was used as a superplasticiser that fulfils ASTM C494 [17]. The mixture is watery and dry using a ratio of 0.24 water to 1 cement (0.24:1), and a ratio of 0.25 silica fume to 1 cement (0.25:1). The particles of river sand used in this study are smaller than 1.18 millimetres in size, and its cement-to-sand ratio is 1:0.57. Cement is utilised at a rate of 775 kg/m^3 in the control mix design of batch 0 (B0), and cement is partially replace by 4% of quarry dust in the mix design of batch 4 (B4), 8% in the mix design of batch 8 (B8), and 12% in the mix design of batch 12 (B12). The UHPC constituent are mixed using high speed mixer in contrast to normal concrete which mixed normal mixer and even manually, and this is due to reduced amount of water in UHPC. First, the sand and silica fume were mixed for almost 5 minutes at 120 r/min. Then, the quarry dust is added while the bowl is spinning. Finally, as the mixer continued to spin, mixture of water and plasticizer is added to the dry ingredients. The mixing process contuened to almost 10 minutes until the UHPC reached adequate consistency. Fig. 1(a) shows a ready mix of the UHPC and Fig. 1(b) shows moulds containing the UHCP.

After the UHPC is mixed, its workability was measured using a slump test according to BS EN 12350-2 [18]. The UHPC samples were cure in normal water under ambient temperature. Compression, tensile, and flexural tests were performed on samples to ascertain the impact of quarry dust on the strength of UHPC. These test were conducted after day 7th, 14th and 28th of curing. Compressive tests on 50 mm cubes were conducted in accordance with BS6319-Part 2, tensile splitting tests on 100mm cylinders were performed in adherence to BS EN 12390-60, and flexural tests on 75mm x 300mm rectangular beams were completed following BS EN 12390-5 [19].



(a) (b)

Fig. 1 - (a) UHPC mix in high speed mixer; (b) moulds containing UHPC

Furthermore, this research also investigated the impact of quarry dust on the long-term durability of the UHPC. The water absorption test was carried out under BS1881: Part 122-1983 [20]. After 25 days in water, 100 mm cubes of UHPC were dried and kept in an oven at 105 °C for three days (72 hours). Every sample was cooled in a dry airtight container for 25+0.5 hours after being taken out of the oven, then soaked the dry samples for the next 35 minutes in water. The experiment's outcome was derived from the difference in mass between the dry and wet samples. After 28 days of water curing, RCPT tests were executed on cylindrical samples of UHPC measuring 100mm in diameter and 50mm in length according to ASTM C120 [21]. The specimens of UHPC were tested for resistivity to chloride ions by subjecting them to an electrical conductivity test. This test evaluates the depth to which chloride ions have penetrated the UHPC, which is vital because chloride ions are a key source of corrosion for embedded steel. Following that, carbonation depth tests were undertaken based on BS: EN 14630 [22]. The carbonated layer near the surface of the hardened concrete is detected using an indicator of phenolphthalein solution with a pH value of approximately 9.

SEM (scanning electron microscope) analysis was performed on the samples to map the bonding between the various concrete constituents of the UHPC mixes and determine the average size of silica fume, cement, and quarry dust. For this purpose, the SU3500 Scanning Electron Microscope Machine inspects the grounded form of four different batches. The Design-Expert programme is utilised to ascertain the optimal percentage based on adaptable strength criteria. This analytical programme represents a highly effective means of accomplishing these goals. The response surface methodology (RSM) is one of the most familiar approaches. It is common to practise utilising the RSM technique because of its efficacy in illuminating the connection between inputs and outputs. In addition, RSM has several advantages. It can accurately forecast the model for responses, be constructed with a small quantity of experimental data, and capture the interaction between the elements. For this goal, a linear model was developed for each response using the historical data obtained from experimental work on B0, B4, B8, and B12 and RSM's well-known central composite design (CCD) model. Linear modelling and analysis of variance (ANOVA) were applied to assess the impact of quarry dust on the mechanical characteristics of UHPC at concentrations of more than 12%, allowing for the prediction of optimal values and the amplification of relations between the given range parameters. In Design-Expert version 12, a response surface model based on a central composition design using linear models for responses was utilised in a series of statistical trials.

3. Result and Discussion

3.1 Physical Properties of The UHPC

Table 1 displays the XRF analysis performed on cement, silica fume, and quarry dust to determine the chemical composition of these materials. Compared to regular quarry granite stone, which was used as a substitute, the Al_2O_3, SiO_2, and K_2O concentrations in this quarry dust are 17%, 16%, and 48%, respectively [23]. The setting times were shortened for UHPC due to the addition of Al_2O_3, and this effect is exhibited in regular concrete [24]. Due to its low CaO content, quarry dust powder diminishes the pozzolanic feature in UHPC blends. The compressive strength of UHPC is improved by silica fume due to its tiny particles and pozzolanic quality.

In both quarry dust and silica fume, SiO_2 constitutes the densely concentrated component. The percentage of Al_2O_3 in the stone dust is 10.6%. Granular constituent of the UHPC are quite fine compare to normal concret. Sand is the largest particle in the UHPC matrix with maximum particle size of around 1.2 mm. The result of sieve analysis for fine sand is shown in Fig. 2.

Table 1 - Chemical composition of OPC, QD, and SF

Chemical composition	OPC	SF	QD
SiO_2 (%)	17.58	97	58.78
CaO (%)	67.98	<0.005	<0.005
Fe_2O_3 (%)	4.47	0.5	1.39
Al_2O_3 (%)	3.37	0.2	10.68
K_2O (%)	0.81	0.5	4.19
SO_3 (%)	4.36	<0.005	<0.005
MgO (%)	<0.005	<0.005	0.59

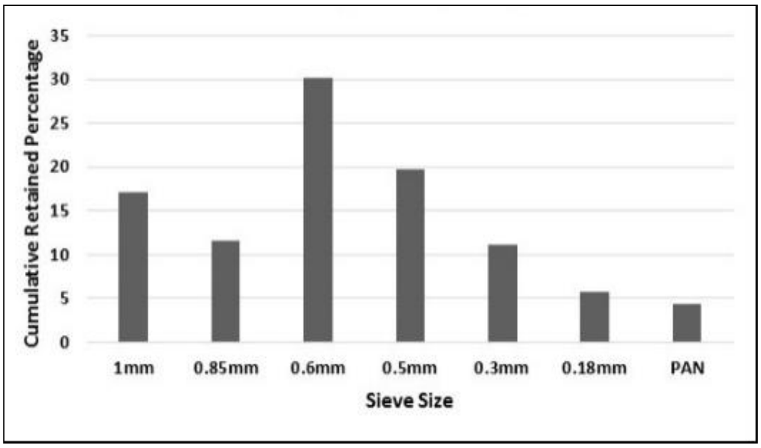
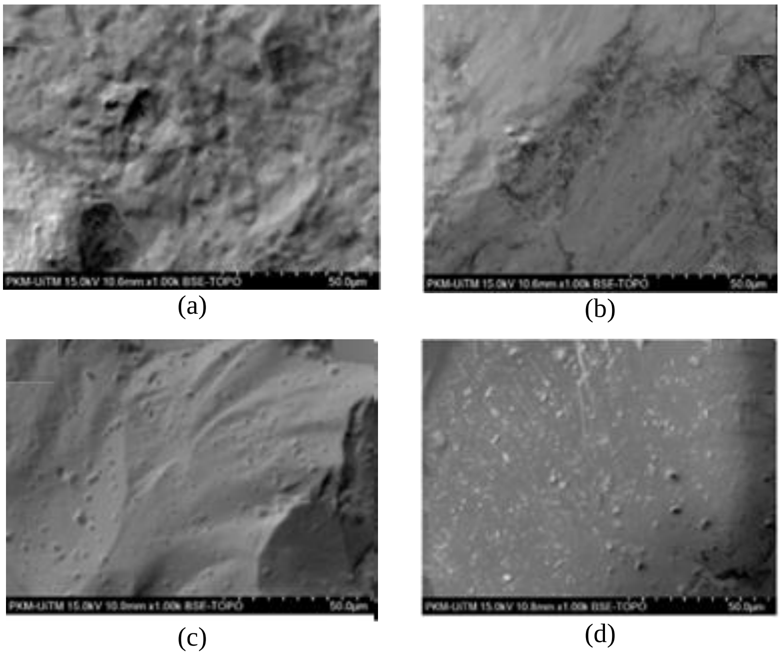


Fig. 2 - Result of sieve analysis for fine sand

Referring to Fig. 2, more than 50% of fine sand is more than 0.6mm in particle size that improve the granular packing of the UHPC. The OPC particle size ranges between 1-50µm, the SF particle size ranges between 0.1 - 0.3 µm, and the quarry dust partical size ranges between 1-100 µm. The result of SEM test is shown in Fig. 3.


(a) (b)

(c) (d)

Fig. 3 - BSE - TOPO image of the UHPC at the scale of 50.0 µm; (a) B0; (b) B4; (c) B8; (d) B12

Scanning electron microscopy (SEM) was employed to gain in-depth knowledge of how quarry dust affects the UHPC's surface topography. Fig. 3 represents SEM images of the UHPC with 0%, 4%, 8%, and 12% of quarry dust as a partial replacement of cement represent by B0, B4, B8, and B12 batches. Applying a scale of 50 µm, the photos reveal the morphology and texture of the UHPC. The UHPC with a surface containing 12% quarry dust, Fig. 3(d), has a substantially smoother texture than B0 batche's surface. Similarly, B4 and B8 have a smoother surface than the control mix or B0. It follows that the surface smoothness of the UHPC improves with an increase in the percentage of quarry dust. As result, quarry dust as partial replacement of cement affect surface topography crystallization fo the UHPC.

3.2 Mechanical Properties of The UHPC

Compressive strength in concrete is the most important parameter of a concrete, and it is significantly high in the UHPC. Fig. 4 displays the results of a compressive strength test conducted on 7, 14, and 28 days of curing samples of the four mixes.

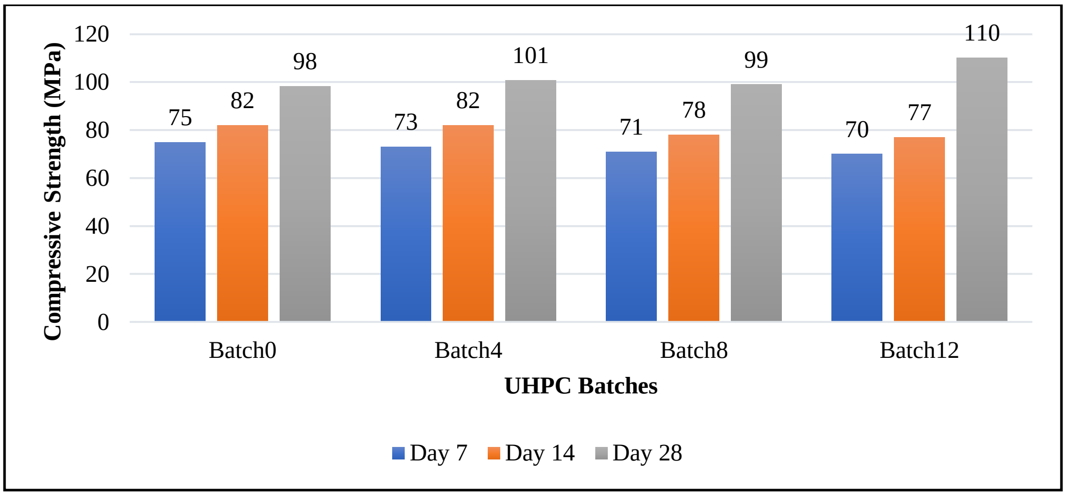


Fig. 4 - Compressive strength test results

On days 7 and 14, the compressive strength was higher for B0 with 0% quarry dust compared to other batches, but after day 28, B12 compressive strength had surpassed B0's compressive strength by 10.8%. As a result, it can be deduced that quarry dust slightly retarded the pozzolanic process during the first days of curing, so the compressive strength gradually decreases over 14 days when the OPC is partially replaced by quarry dust. However, quarry dust improved the compressive strength on day 29th. Yang et al. [25] corroborated a similar discovery regarding the increasing the amount of quarry dust increases compressive strength. More cement causes an early-stage excessive pozzolanic reaction, which causes strength fluctuations. In the UHPC, the availability of Al_2O_3 in quarry dust slows down the pozzolanic response and its fine particle increases the compactness of the UHPC. Although using quarry dust as a cement replacement in conventional concrete decreases its compressive strength [23]. The effect of quarry dust on tensile strength of the UHPC is opposite to its compressive strength as it reduces its tensile strength. The result of splitting tensile strength which is an undirect tensile strength test after 7, 14, and 28 days of curing is shown in Fig. 5.

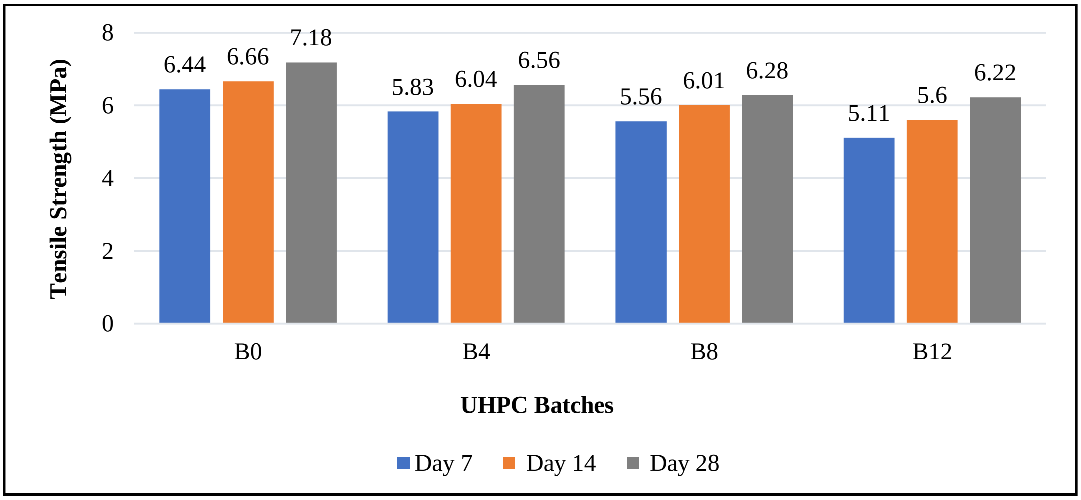


Fig. 5 - Splitting tensile strength test result

As can be seen in Fig. 5, the tensile strength of the UHPC is reduced when cement is partially substituted with quarry dust, revealing contrasting outcomes to the compressive strength. The amount of quarry dust used is inversely proportional to this decline. There was a 10.3% improvement in tensile strength from day 7th to day 28th of curing in B0, ,the control batch, but when the quarry dust is used as substitution for 12% of the cement, the tensile strength droped by about 13% after during that period of curing. Between days 7 and 14 in B0, there is a 3.3% variation in tensile strength, but this increased to 8.7% in B12. There is a linear reduction in tensile strength of the UHPC in relatition to increase in percentage of quarry dust used. Similar to B0 and B12, there is slight tensile strength fluctuation in B4 and B8 wich are 11.1% and 11.4% from day 7 to day 28 of curing respectively. Therefore, quarry dust does not accelerate the pozzolanic processes and does not enhance the bonding in the UHPC as substantially as cement does between the UHPC's matrix. The effect of quarry dust on flexural strength of the UHPC is similar to its effect on tensile strength. So, UHPC's flexural strength is further reduced by quarry dust. The result of flexural strength test for day 7th, 14th, and 24th of curing is shown in Fig. 6.

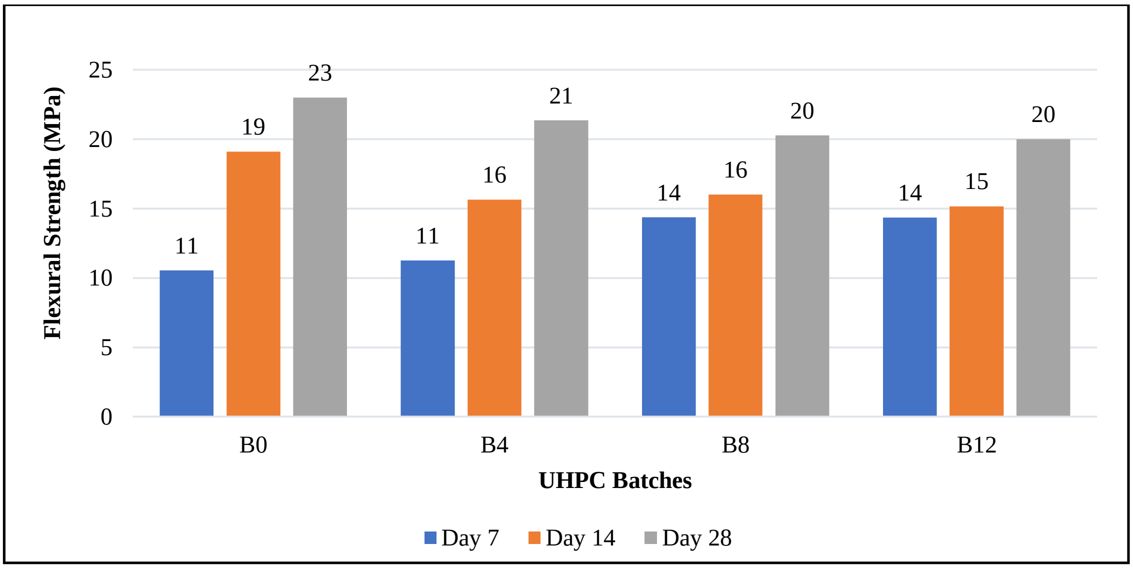


Fig. 6 - Flexural strength test result

The flexural test result indicates that the flexural strength had a linear decline from B0 to B12, or it linearly declined by increase of quarry dust in the UHPC. B0 had the highest flexural strength (23 MPa) compared to B4, B8, and B12. After 28 days of curing, the flexural strength was reduced by 12% in B12 compared to B0. From 7 to 28 days of curing, the flexural strength rose by about 54% in batch 0 and by 28% in batch 12. However, the flexural strength of B0 is 26% lower than B12 after 7 days of curing. So, quarry dust retard the flexural strength gain in early days of curing and act as filler to improve the strength, but it reduces bonding between granular particles of the UHPC that affects flexuraly strength negatively in later stage of curing. This disparity can be attributed to a lessening of the pozzolanic reaction and improvement of compactness by quarry dust in the UHPC.

3.3 Durability Properties of the UHPC

UHPC is highly durable concrete, and this durability is because of its specific matrix. Since all granular constituents of the UHPC is smaller than 1.2 mm, it is a compact and dense concrete. The water absorption test showed that none of the four batches had absorbed more than 0.5% of the total mass in water. The proportion of water absorbed by the B0 is the greatest among the four UHPC mixtures. A progressive decrease while adding B4, B8, and B12 in water absorption was detected in UHPC. The small particles of quarry dust produce a compact environment, which contributes to reduce voids and avoid the absorption or peneteration of water. For this reason, the UHPC made with quarry dust has a minimal capacity to absorb water. For aggressive environmental exposure the BS 6349 standard limit water absorption of structure to 2% or 3%. So, water permeability is disregarded for UHPC because it is far lower than the allowable limit stated in the standard.The result of water absorption test is shown in Fig. 7.

Fig. 8 shows the result of RCPT on the UHPC after 28 days of curing. The average value for chloride permeability across four batches is 59 Coulombs, which is significantly low compared to criteria stated in ASTM C1202 standard, and the different level of Chloride Ion permeability are written in Table 2 [21]. In B0, 70 coulombs is the maximum passing charges, and it decreased significantly down to 58, 55, and 53 coulombs after adding B4, B8, and B12 respectively.

The drop in chloride ions results from the rise in tiny particles of quarry dust, which causes the porosity of UHPC to decrease slightly [26]. As result, the UHPC keeps embedded reinforcement less exposed to corrosion. Despite Chloride Ions, embedded steel in UHPC is also vulnerable to corrosion from carbon attack; hence the carbonation depth test is crucial for determining this parameter. After 28 days of curing ,all specimens of the B0, B4, B8, and B12 batches were tested for carbonation using phenolphthalein. The result of carbonation depth B0, B4, B8, and B12 is less than the detection threshold (0.1 mm). As a result, the relative corrosion resistance of implanted steel is enhanced when quarry dust is used in place of cement.

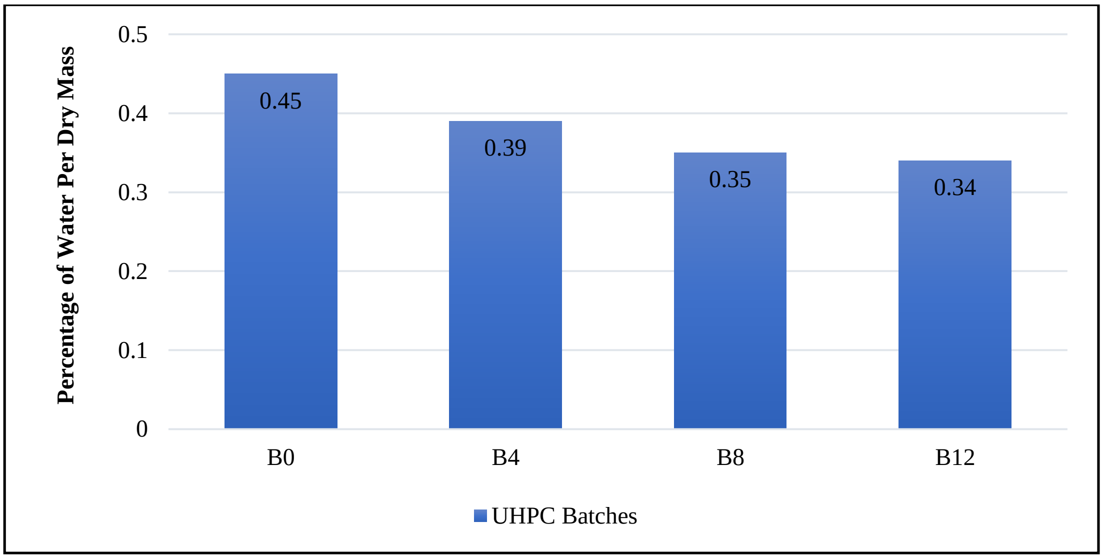


Fig. 7 - Water absorption test result

Table 2 - Criteria for rapid chloride permeability test by ASTM C1202 [21]

Measured Value, Coulombs	Chloride Ion Penetrability
>4000	High
4000 - 2001	Moderate
2000 - 1001	Low Very
1000-101	Low
< 100	Negligible

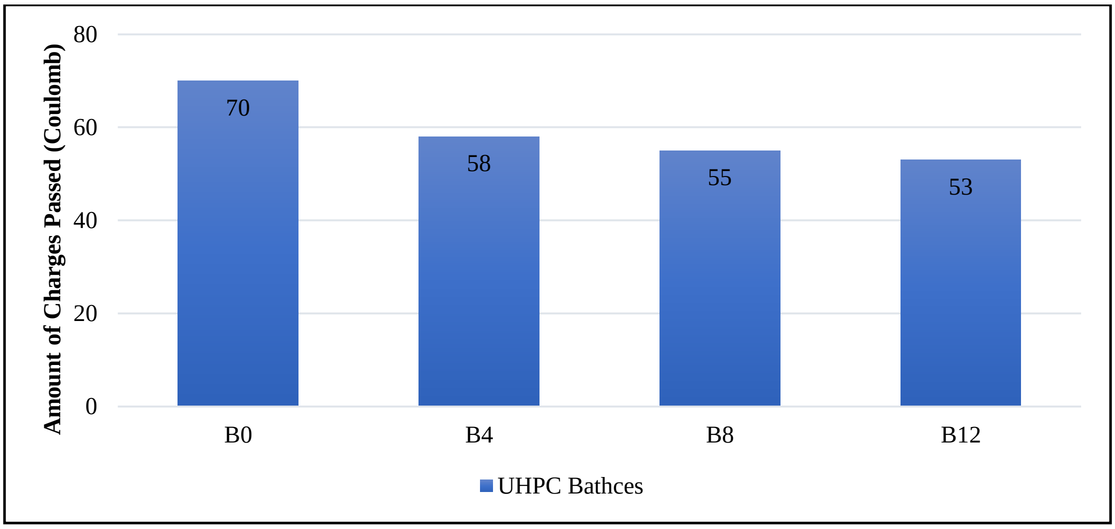


Fig. 8 - Rapid chloride per results

3.4 Optimization of Quarry Dust Percentage Using Design - Expert Software

Design-Expert Software applied the surface response method (SRM) to predict the impact of using more than 12% quarry dust as a cement substitute. Therefore, applying the strength and percentage of quarry dust as varying parameters in Design Expert software due to the almost insignificant impact of quarry dust on durability. The experimental result history served as the input data. The significance of the past data was validated by the linear model and analysis of variance (ANOVA) results. Fig. 9 compares the theoretical and empirical models for the impact of the quarry on the UHPC's ultimate strength

Furthermore, Fig. 9 also demonstrates that both the forecast made by the surface response model and the historical data is relatively close to the line. Predictions of the response for specified levels of each element can be made using the equation expressed in coded factors (variable parameters). The default encoding for a given factor assigns a value of +1 to its maximum and -1 to its minimum. The relative importance of the elements can be determined by comparing the factor coefficients in the encoded equation.

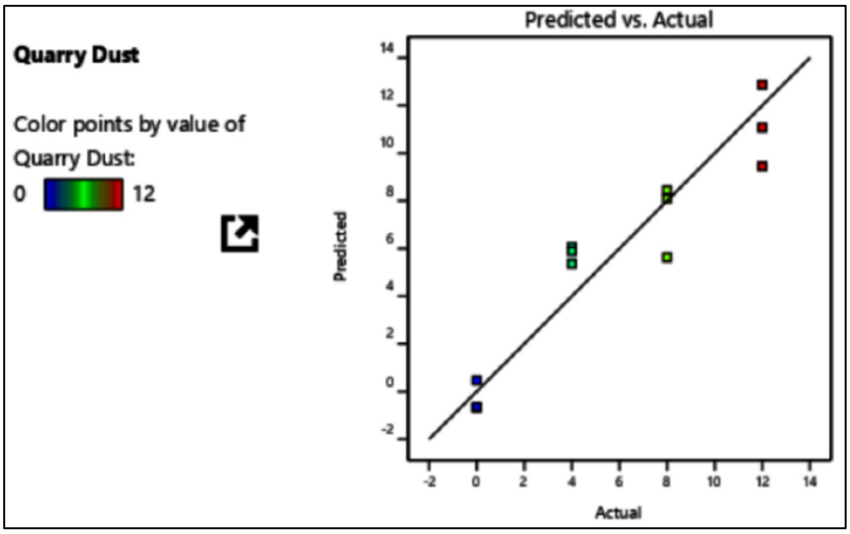


Fig. 9 - The efficiency of the predicted model compared to actual historical data

This leads to the following equation in terms of encoded variables:

$$\text{Quarry Dust} = +6.91 + 4.14A - 10.67B + 1.44C \tag{1}$$

where A, B, and C are the material's compressive, tensile, and flexural strengths, respectively. The answer for a given level of each factor can be predicted using the equation in terms of actual factors. The levels for each factor should be listed here using their original units. However, this equation is unsuitable since the coefficients are scaled to suit the units of each element and the intercept is not at the centre of the design space to evaluate the relative impact of each factor. Ultimately, the equation expressed in terms of real-world inputs is as follows:

$$\text{Quarry Dust} = +47.78965 + 0.206195f_{cu} - 10.30578f_t + 0.230592f_f \tag{2}$$

where f_{cu} is compressive strength, f_t is tensile strength, and f_f is flexural strength. The Design-Expert programme determined that a proportion of 21.85% quarry dust would be the maximum allowable while allowing for sufficient compressive, flexural, and tensile strengths for UHPC. Model predictions show that using 21.85% quarry dust increases the concrete's compressive strength to 107 MPa, tensile strength to 5.2 MPa, and flexural strength to 21.2 MPa. Meanwhile, the compressive strength at this quarry dust percentage is 110 MPa, tensile strength at 6.5 MPa, and flexural strength at 23 MPa. Design-Expert programme showed that 8.6% quarry dust would provide the best compromise between maximal compressive, tensile, and flexural strengths.

4. Conclusion

This research aimed to examine the performance of UHPC with quarry dust used as a partial cement replacement. UHPC optimised with up to 12% of recovered quarry dust as a partial replacement of cement was tested to establish its strength and durability. Following this, the experimental data was then input into Design-Expert software to make predictions on the durability of UHPC with more than 12% quarry. This study's main finding is as regards: After 14 days of drying, UHPC, including recovered quarry dust, had greater compressive strength than the control mix. However, the compressive strength of the control mix is higher in the wet stage of curing. The flexural strength of UHPC is marginally reduced when applying recovered quarry dust in place of cement. The UHPC's tensile strength reduced by increase in percentage of quarry dust. The UHPC's durability was moderately enhanced due to substituting recycled quarry dust as an altered cement element. According to Design-Expert, the optimal proportion of recycled quarry dust applied to keep the UHPC's strength within the range with maximum compressive strength is 21.85%. However, further experiments will be needed to validate the predicted result of the software. The SEM results show that the recycled quarry dust makes the

UHPC's surface topography more uniformly flat and smooth than the control mix. The condition has a direct relation with the proportion of quarry dust. Recycled quarry dust can be used as a filler in the matrix of UHPC, reducing the amount of hydration in UHPC.

Acknowledgement

The authors would like to express their gratitude to the Universiti Teknologi MARA, Shah Alam for supporting this publication via research grant 100-RMC 5/3/SRP INT (043/2022).

References

[1] ACI PRC-239-18 (2018). Ultra-High Performance Concrete: An Emerging Technology Report. American Concrete Institute.

[2] Kajaste R. & Hurme M. (2016). Cement industry greenhouse gas emissions e management options and abatement cost. Journal of Cleaner Production, 112, 4041-4052. https://doi.org/10.1016/j.jclepro.2015.07.055

[3] Yu R., Spiesz P. & Brouwers H. J. H. (2014). Effect of nano-silica on the hydration and microstructure development of Ultra-High Performance Concrete (UHPC) with a low binder amount. 65, 140-150. https://doi.org/10.1016/j.conbuildmat.2014.04.0

[4] Kara De Maeijer P., Craeye B., Snellings R., Kazemi-Kamyab H., Loots M., Janssens K. & Nuyts G. (2020). Effect of ultra-fine fly ash on concrete performance and durability. Construction and Building Materials, 263, 120493. https://doi.org/10.1016/j.conbuildmat.2020.120493

[5] Vo D. H., Hwang C. L., Tran Thi K. D., Yehualaw M. D. & Chen W. C. (2020). Effect of fly ash and reactive mgo on the engineering properties and durability of high-performance concrete produced with alkali-activated slag and recycled aggregate. Journal of Materials in Civil Engineering, 32(11), 04020332. https://doi.org/10.1061/(asce)mt.1943-5533.0003420

[6] Bahedh M. A. & Jaafar M. S. (2018). Ultra high-performance concrete utilizing fly ash as cement replacement under autoclaving technique. Case Studies in Construction Materials, 9, e00202. https://doi.org/10.1016/j.cscm.2018.e00202

[7] Yigiter H., Aydin S., Yazici H. & Yardimci M. Y. (2012). Mechanical performance of low cement reactive powder concrete (LCRPC). Composites Part B: Engineering, 43(8), 2907-2914. https://doi.org/10.1016/j.compositesb.2012.07.042

[8] Van Tuan N., Ye G., Van Breugel K. & Copuroglu O. (2011). Hydration and microstructure of ultra high performance concrete incorporating rice husk ash. Cement and Concrete Research, 41(11), 1104-1111. https://doi.org/10.1016/j.cemconres.2011.06.009

[9] Li P. P., Brouwers H. J. H., Chen W. & Yu Q. (2020). Optimization and characterization of high-volume limestone powder in sustainable ultra-high performance concrete. Construction and Building Materials, 242. https://doi.org/10.1016/j.conbuildmat.2020.118112

[10] Qian D., Yu R., Shui Z., Sun Y., Jiang C., Zhou F., Ding M., Tong X. & He Y. (2020). A novel development of green ultra-high performance concrete (UHPC) based on appropriate application of recycled cementitious material. Journal of Cleaner Production, 261, 121231. https://doi.org/10.1016/j.jclepro.2020.121231

[11] Yang R., Yu R., Shui Z., Gao X., Han J., Lin G., Qian D., Liu Z. & He Y. (2020). Environmental and economical friendly ultra-high performance-concrete incorporating appropriate quarry-stone powders. Journal of Cleaner Production, 260, 121112. https://doi.org/10.1016/j.jclepro.2020.121112

[12] Liu T., Wei H., Zou D., Zhou A. & Jian, H. (2020). Utilization of waste cathode ray tube funnel glass for ultra-high performance concrete. Journal of Cleaner Production, 249, 119333. https://doi.org/10.1016/j.jclepro.2019.119333

[13] Smarzewski P. (2020). Mechanical properties of ultra-high performance concrete with partial utilization of waste foundry sand. Buildings, 10(1), 1-15. https://doi.org/10.3390/buildings10010011

[14] BS ISO 29581-2 (2010). Cement - Test methods - Part 2: Chemical analysis by X-ray fluorescence. British Standard Institution.

[15] Wille K., Naaman A. E. & El-Tawil S. (2011). Optimizing ultra-high-performance fiber-reinforced concrete: Mixtures with twisted fibers exhibit record performance under tensile loading. Concrete International, 33(9), 35-41.

[16] Hüsken G. & Brouwers H. J. H. (2008). Earth-moist concrete: Application of a new mix design concept. Cement and Concrete Research, 38(10), 1246-1259.

[17] American Society for Testing and Materials (1999). Standard Specification for Chemical Admixtures for Concrete. Annual Book of ASTM Standards, Concrete and Mineral Aggregates.

[18] BS EN 12350-2 (2009). Testing fresh concrete. Slump-test. British Standard Institution.

[19] BS EN 12390-3(2009). Testing hardened concrete. Compressive strength of test specimens. British Standard Institution.

[20] BS 1881-122 (1883). Methods for determination of water absorption. British Standard Institution.

[21] ASTM-C1202-12 (2007). Standard test method for electrical indication of concrete's ability to resist chloride ion penetration. ASTM International.

[22] BS EN 14630 (2006). Determination of carbonation depth in hardened concrete by the phenolphthalein method. British Standard Institution.

[23] Kartini K., Hamidah M. S., Norhana A. R. & Nur Hanani A. R. (2014). Quarry dust fine powder as substitute for ordinary portland cement in concrete mix. Journal of Engineering Science and Technology, 9(2), 191-205.

[24] Hu Z., Teng Y., Wang Q. & Wu L. (2018). Dielectric properties of CaCu 2.9 Zn 0.1 Ti 4 O 12 ceramics by addition of Al2O3 nanoparticles. Journal of Materials Science: Materials in Electronics, 29, 9245-9250. http://dx.doi.org/10.1007/s10854-018-8953-z

[25] Yang R., Yu R., Shui Z., Gao X., Han J., Lin G., Qian D., Liu Z. & He Y. (2020). Environmental and economical friendly ultra-high performance-concrete incorporating appropriate quarry-stone powders. Journal of Cleaner Production, 260, 121112. https://doi.org/10.1016/j.jclepro.2020.121112

[26] Sohail M. G., Kahraman R., Al Nuaimi N., Gencturk B. & Alnahhal W. (2021). Durability characteristics of high and ultra-high performance concretes. Journal of Building Engineering, 33, 101669. https://doi.org/10.1016/j.jobe.2020.101669