Advances in Concrete Construction, *Vol. 5, No. 5 (2017) 481-492*
DOI: https://doi.org/10.12989/acc.2017.5.5.481

Effect of quartz powder, quartz sand and water curing regimes on mechanical properties of UHPC using response surface modelling

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(Received April 27, 2017, Revised September 10, 2017, Accepted September 12, 2017)

Abstract. The aim of this paper is to investigate the effect of quartz powder (Qp), quartz sand (Qs), and different water curing temperature on mechanical properties including 7, 14, 28-day compressive strength and 28-day splitting tensile strength of Ultra High Performance Concrete and also finding the correlation between these variables on mechanical properties of UHPC. The response surface methodology was monitored to show the influences of variables and their interactions on mechanical properties of UHPC, then, mathematical models in terms of coded variables were established by ANOVA. The offered models are valid for the variables between: quartz powder 0 to 20% of cement substitution by cement weight, quartz sand 0 to 50% of aggregate substitution by crushed limestone weight, and water curing temperature 25 to 95ºC.

Keywords: ultra high performance concrete; quartz powder; quartz sand; different water curing temperature

1. Introduction

Ultra High Performance concrete (UHPC) is a superior composite with the special properties in ductility, compressive and tensile strength (Wang 2014). UHPC is a matrix of main ingredient materials like fine aggregate, fiber, superplasticizer, and large dosage of cement and silica fume (Reddy and Elumalai 2014, Afra *et al.* 2010). However, by adding some other admixture like quarts powder (Qp) and Quartz sand (Qs) and using different methodologies like curing temperature can improve the properties of UHPC.

At the beginning, UHPC with name of reactive powder concrete (RPC) or ultra-high performance ductile concrete (UHPdC) in 1990s was developed by Richard and Cheyrezy, that introducing of UHPdC considered as one of the amazing developments in the field of concrete technology (Richard and Cheyrezy 1995). Later on, many researches on the UHPC were done to improve the performance Aldahdooh *et al*. 2013). Prem *et al.* (2015) worked on strength of UHPC with and without fiber in different curing condition regimes and reported that the optimum thermal

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http://www.techno-press.org/?journal=acc&subpage=7 ISSN: 2287-5301 (Print), 2287-531X (Online)

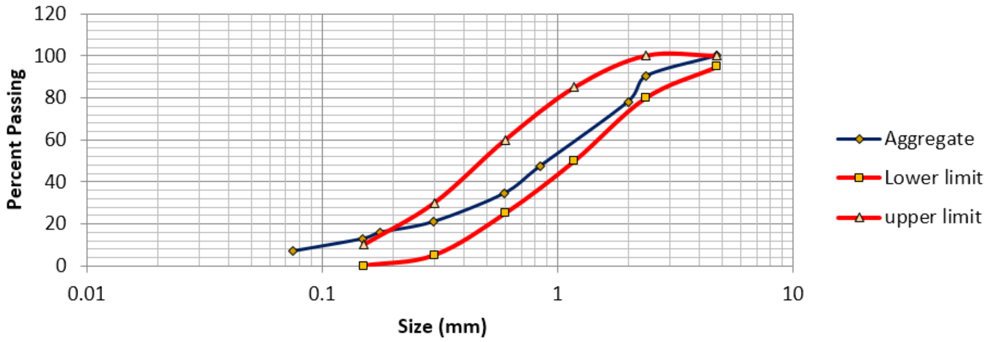


Fig. 1 Size analysis of aggregate

curing of UHPC is 48 hours after molding-out (ToledoFilho *et al.* 2012). Reda *et al.* (1999) was reported that thermal curing is converting weak Calcium hydroxide (CH) to strong Calcium silicate hydrate (C-S-H) gel during hydration.

Ambily *et al.* (2013) was developed the particle packing on compressive strength of UHPC. Yazici (2007) worked on the effect of combining silica fume, pulverized granulated blast furnace slag with Portland cement, quartz powder and basalt were used as an aggregate with three different curing regimes. Reddy *et al.* (2014) studied the macro mechanical properties of UHPC by using quartz powder as an aggregate and silica fume with different curing regimes.

Response surface methodology (RSM) is a mixture between mathematics and statistics techniques, and could be used for analyzing and modeling different factors to reach a good interpretation by finding the relations between variables to achieve the optimum response (Kumar *et al.* 2012, Mohammed *et al.* 2014). De Larrard and Sedran (1994) by using particle packing model found the mix proportion or Yu *et al.* (2014) modified Anderasen and Anderson particle packing model.

UHPC is normally consuming cement more than three times of normal strength concrete by large amount of ordinary cement between 900-1000 kg/m^3 which is concluding using more energy and producing more carbon dioxide (Mosaberpanah and Eren 2016). This paper is trying to model and analyze the effect of quartz powder as cement substitution in side of considering the effect of quartz sand as aggregate substitution and thermal water curing separately and together on mechanical properties of UHPC using response surface methodology.

2. Experimental activities

2.1. Materials

2.1.1 Cement

Type 2, 42.5 Mpa slag portland sulfate resisting cement was used which satisfies by European standard EN 197-1 (2002). Percentage amount of slag and clinker for manufactured cement were 21-35% and 65-79%, respectively.

2.1.2 Aggregate

In this study crushed limestone maximum particle size of 5 mm was used as an aggregate.

Table 1 Chemical analysis of quartz powders

Crushed quartz powders chemical analysis	
Component	Percentage (%)
LOI	0.05
SiO_2	99.26
Al_2O_3	0.33
Fe_2O_3	0.027
TiO_2	0.023
CaO	0.01
MgO	0.08
Na_2O	0.01
K_2O	0.21

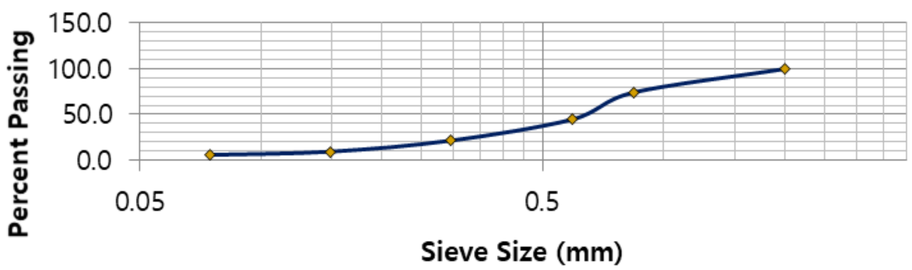


Fig. 2 Size distribution of crushed quartz sand

Sieve analysis was done following ASTM C136 (1995) and controlled using ASTM C33 (2004) as shown in Fig. 1.

2.1.3 Water

Ordinary tap water was used for mixing and curing process.

2.1.4 Superplasticizer

Superplasticizer was high range water reducer with the base of polycarboxylic ether developed for using in UHPC which is known as GLENIUM27 and consistent with EN 934-2 (2009).

2.1.5 Steel fiber

The diameter and length of steel fiber used was 0.55 and 13 mm with elasticity modulus of 210 GPa and tensile strength of 1345 MPa which was manufactured by company of Dramix and confirmed following ASTM A820 .

2.1.6 Micro silica fume

Micro white undensified silica fume with the purity of more than 95% of silicon dioxide with particle size 0.1-1 μm was consumed.

2.1.7 Quartz powder (Qp)

The crushed quartz powder was used as cement substitution with the particle size of less than

Table 2 Design of experiments

Mix no.	Qp	Qs	Curing	Qp	Qs	Curing
	Codes			(%)	(%)	°C
	A	B	C	A	B	C
1	0	0	1	10	25	85
2	0	0	0	10	25	55
3	0	0	0	10	25	55
4	-1	-1	1	0	0	85
5	1	1	-1	20	50	25
6	0	0	-1	10	25	25
7	-1	1	-1	0	50	25
8	-1	0	0	0	25	55
9	-1	1	1	0	50	85
10	1	0	0	20	25	55
11	1	1	1	20	50	85
12	-1	-1	-1	0	0	25
13	1	-1	1	20	0	85
14	1	-1	-1	20	0	25
15	0	1	0	10	50	55
16	0	-1	0	10	0	55

Table 3 The variables levels

Variables	Coding	Low level -1	Intermediate level 0	High level +1
Quartz powder	A[a]	0%	10%	20%
Quartz sand	B[b]	0%	25%	50%
Water curing	C[c]	25°C	55°C	85°C

a:percentage of aggregate substitution by aggregate mass, b: percentage of cement substitution by cement mass, c: different water curing temperature

0.125 μm. the Chemical analysis to find the purity percentage was done which is shown in Table 1.

2.1.8 Quartz sand (Qs)

The crushed quartz sand was used as an aggregate substitution which replaced by crushed lime stone sand. It was in form of yellowish-white with particle size between 0.125 μm and 200 μm. the sieve analysis is given in Fig. 2.

2.2 Experimental design

The experiments were designed and randomized using design of experiment (DOE). DOE is a way to find the effect of indeterminate variables on different responses by making minimum experiments. In order to screen the results central composite face centered design (CFC) was

Table 4 UHPC mix proportion

Mix	Aggregate (kg/m^3)	Silica Fume (kg/m^3)	Cement (kg/m^3)	Steel Fiber (kg/m^3)	Super plasticizer (kg/m^3)	Water (kg/m^3)	W/C Ratio
Amount	1244	187	870	250	50	190	0.18

Table 5 Mix design details of UHPC

NO	Crushed limestone sand	Silica Fume	Cement	Steel Fiber	Super plasticizer	Water	W/C	Qp	Qs	Water curing temperature
#	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	--	kg/m^3	kg/m^3	°C
1	933	187	783	250	50	190	0.18	87	311	85
2	933	187	783	250	50	190	0.18	87	311	55
3	933	187	783	250	50	190	0.18	87	311	55
4	1244	187	870	250	50	190	0.18	0	0	85
5	622	187	696	250	50	190	0.18	174	622	25
6	933	187	783	250	50	190	0.18	87	311	25
7	622	187	870	250	50	190	0.18	0	622	25
8	933	187	870	250	50	190	0.18	0	311	55
9	622	187	870	250	50	190	0.18	0	622	85
10	933	187	696	250	50	190	0.18	174	311	55
11	622	187	696	250	50	190	0.18	174	622	85
12	1244	187	870	250	50	190	0.18	0	0	25
13	1244	187	696	250	50	190	0.18	174	0	85
14	1244	187	696	250	50	190	0.18	174	0	25
15	622	187	783	250	50	190	0.18	87	622	55
16	1244	187	783	250	50	190	0.18	87	0	55

selected.

2.3 Methodology

In this research, based on RSM, Effect of Quartz Powder, Quartz Sand and Curing on Mechanical Properties of Ultra High Performance Concrete and the interaction of variables were monitored. The response surface modeling used was central composition design with α=1 (face centered) and linear or quadratic models for responses. The interaction between variables and the effect on responses were analyzed by ANOVA. The statistical software “Design-Expert version 9.0.3”, Stat-Ease, Inc., was used to analyze the experimental design. Design of experiment table is given in Table 2.

In this study, mechanical properties of UHPC was investigated as: the 7-day compressive strength, 14-day compressive strength, 28-day compressive strength as well as splitting tensile were denoted as responses and 3 variables as Quartz Powder (A), Quartz Sand (B), Different water curing temperature (°C) are defined to explain the modeling. The range of variables were selected

Table 6 Responses result of UHPC mixtures

Qp	Qs	Curing Regimes	Compressive Strength (MPa)			Splitting tensile strength (MPa)
			7-day	14-day	28-day	
-1	-1	-1	91.0	101.0	111.0	17.0
		1	116.8	121.0	122.0	15.2
	0	0	115.0	119.0	118.0	15.0
	1	-1	82.7	99.0	107.0	11.9
		1	120.0	123.0	124.0	14.1
0	-1	0	118.0	120.0	122.9	16.0
	0	-1	91.0	105.7	116.5	16.6
		0	120.8	121.5	123.4	14.7
			120.0	122.0	124.0	14.0
		1	122.0	122.0	124.0	17.9
	1	0	120.0	118.5	125.2	11.5
1	-1	-1	90.0	105.0	114.0	14.2
		1	125	124.4	124.0	15.8
	0	0	120.6	119.7	123.9	15.5
	1	-1	90.0	103.4	120.3	16.0
		1	132.7	129.0	131.5	18.0

Table 7 Analysis of regression models

Response	R^2	Adj-R^2	Pre-R^2	F-Value	Lack of fit	Model P-value
Compressive strength at 7 day	0.996	0.992	0.972	237	0.28	<0.0001
Compressive Strength at 14 day	0.975	0.960	0.935	76.71	0.13	<0.0001
Compressive strength at 28 day	0.984	0.965	0.870	53.00	0.26	<0.0001
Splitting tensile strength at 28 day	0.830				insignificant	0.094>0.05

as follow: Quartz Powder, from 0 to 20 percent of cement mass as cement substitution, the quartz sand content, from 0 to 50 percent of sand mass as sand substitution, and different water curing temperature, from 25 to 85°C. The variables with their level of limitations are given in Table 3.

2.4 Mix proportion

In this study sixteen experiments were designed. Details of mix proportions are given by Table 4.

2.5 Preparation and test of specimens

In this study, 16 mixes were prepared (Table 5). Firstly, premix which is included of dry materials including; aggregate, silica fume, and cement, and if there was quartz except steel fibers were blended in determined proportion of each mix for five minutes, then, superplasticizer and steel fiber were added to water, next, water mix was added to premixed mixture and mixed in

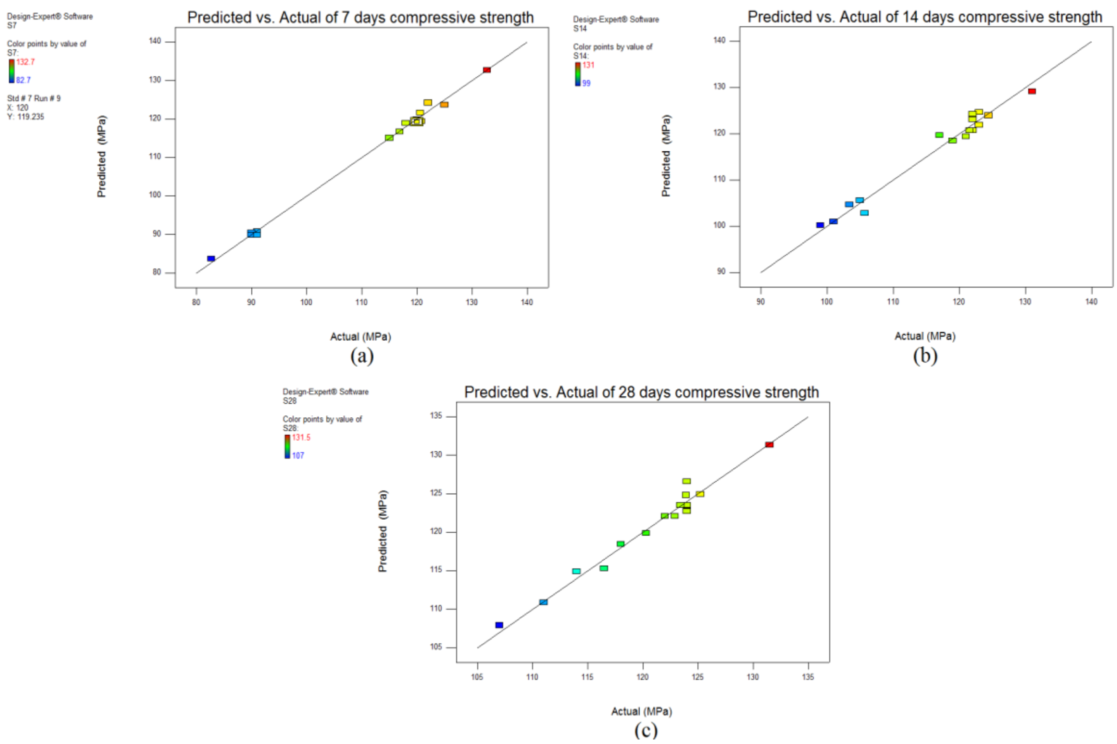


Fig. 3 Prediction of efficiency of offered model for 7, 14, 28-day compressive strength

Table 8 Parameter estimated for models at 7, 14, 28-day compressive strength

	Compressive strength (7-day)		Compressive strength (14-day)		Compressive strength (28-day)	
Parameters	Estimate	Prob > f	Estimate	Prob > f	Estimate	Prob > f
Constant	119.44	---	120.75	---	123.53	---
A	3.28	0.000157	2.28	0.003871	3.17	0.000258
B	0.46	0.341733	1.10	0.101637	1.41	0.019536
C	17.19	2.07E-09	10.73	0.000000	5.67	0.000006
AB	1.61	0.014647	---	---	1.98	0.006922
AC	1.82	0.008218	---	---	-0.85	0.148097
BC	2.39	0.001968	1.53	0.049413	0.90	0.128920
A^2	-1.12	0.216351	---	---	-1.89	0.064973
C^2	-12.42	1.36E-06	-7.20	0.000028	-2.59	0.020013

order to obtain homogeneous paste. Nine 100 mm cubes were molded to determine the compressive strength. Also, three 100×200 mm (D×L) cylinders were casted for 28-day splitting tensile strength. After molding, whole specimen were compacted using table of vibration and then placed in a moist curing room for one day. They were then molded out and moved to the curing water tank temperature in different levels at 25, 55, 85ºC for 48 hours, then were kept to cure on water tank at 25±2°C until testing time.

2.6 Compressive strength test

In order to determination of compressive strength, 100 mm cubes were tested. Concrete compression machine with 3000 kN in capacity was used following ASTM C109. Three samples were tested for each different ages.

2.7 Splitting tensile strength

Splitting tensile was performed through the ASTM C496 “entitled standard test method for splitting tensile strength of cylindrical concrete specimens”. The sample sizes were 100×200 mm (d×l) cylinder tested at 28-day. Standard concrete compression machine was used to do this experiment.

3. Results

The effects of three variables (Quartz powder (Qp), Quartz sand (Qs), thermal water curing) on the mechanical properties (compressive and tensile strength) of UHPC have been analyzed by using response surface method. For producing the model, 16 points were selected such as 8 points for model making, 2 points for replication, and 6 points to consider the lack of fit.

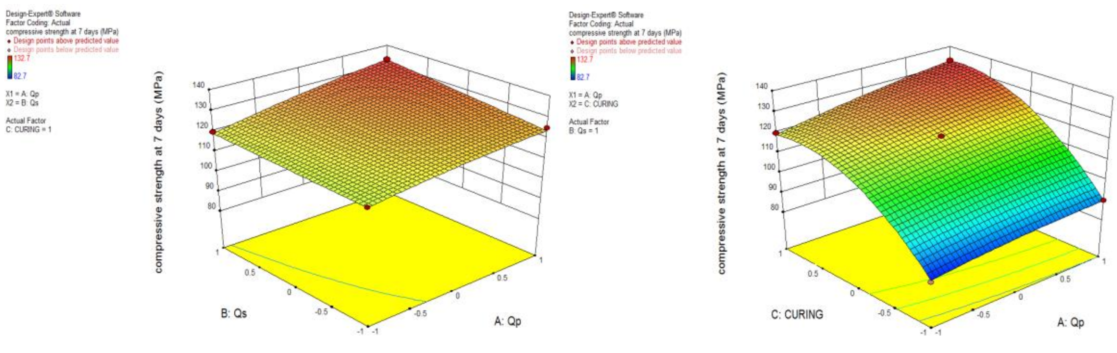
Table 6 shows the results of using three different variables in mechanical properties of UHPC, compressive strength in 7, 14, 28-day, splitting tensile, and modulus of rupture. Each result was derived by average of 3 specimens

The correlation and interaction between variables were considered by analysis of variance (ANOVA). For the modeling, three types of modelling were checked; Linear model, two-factor interaction, and quadratic models. In each model, the significant parameters were detected, therefore, by backward elimination technique the insignificant terms were excluded and final regressions for each responses were taken out. As a result, the quadratic model was selected for all responses. In Table 8, the quality of prediction models were determined by coefficient of multiple determination R2, which shows the total deviation of the variables from the prediction model. The probability of errors (p-value) with confidence level of 95% and statistical significant test at 5% and also lack of fit with p-value greater than 0.05 was performed and checked for model validations.

Analysis of variance showed that the three used variable (quartz powder, quartz sand, thermal water curing) did not have meaningful significant effect on 28-day splitting tensile, whereas, the P value was bigger than 0.05.

The performance of offered prediction models with mechanical responses (7, 14, 28-day compressive strength) for mixture experimental design of UHPC are illustrated in Fig. 3.

Table 8 listed the finalized prediction models to reach the desired performance of compressive and tensile strength of UHPC. Probability factor is given for each parameter. Linear variable A and C are statistically significant factors for all ages compressive strength as shown in Table 8. The quadratic B is not statistically significant factors at the stipulated level of 5%, however, the quadratic C is statistically significant factors at the stipulated level of 5% for all days compressive strength. The significant of some two-way interaction terms are given in 7, 14, 28-day compressive strength in Table 5. A significant two-way interactions explains that the simple effect of a variable is not same at all levels of other variables. The 2-ways interaction of A with B, C (AB, AC), and B



(a) (b)

Fig. 4 Response surface of 7-day compressive strength

with C (BC) are statistically significant factors at the stipulated level of 10% for 7-day compressive strength. In 14-day compressive strength, 2-ways interactions of B with C (CD) is statistically significant factors at the stipulated level of 10%. Also in 28-day compressive strength, the 2-ways interactions of A with B (AB) is statistically significant factor at the stipulated level of 10%.

4. Discussion

Effect of three parameters (quartz powder, quartz sand, different water curing temperatures) on mechanical properties (7, 14, 28-day compressive strength, and 28-day splitting tensile strength) have been considered employing response surface methodology. Effect of variables on responses can be presented graphically by plotting of response value versus variables in different dimensions. The study shows the effect of each variable singularly or with other variables.

The Quartz powder reactivity is very low and slow. To enhance its reactivity, high heat or high pH is needed. That's why the correlation between different water curing temperature was a bit significant in compressive strength modeling of UHPC. On the other side, the Quartz Powder can be used as filler (Sahani and Ray 2014). Thereby, by reducing the initial porosity of the mixture causes to increase the final strength (Sahani and Ray 2014). The different water curing temperature was very effective on compressive strength of UHPC. Its effect of different water curing temperature regimes was more highlighted in 7-day compressive strength than 14, 28-day compressive strength. Raising the temperature increases the rate of hydration, so, the thermal water curing influences more on the early ages. Thermal curing regime enhance shaping of hydrated structures (Yu *et al.* 2014, Wang *et al.* 2015)

4.1 Effect of variables on 7-day compressive strength

Fig. 4(a) shows the 3D plot of Qp and Qs when curing is in lowest level (1). the maximum value of 7-day compressive strength could be seen when all variables values are in mazimum level (1). Fig. 4(b) shows the 3D plot of Qp and effect of water curing temprature changes with maximum level Qs. Highest value of 7-day compressive strenght, with above 45% increase could

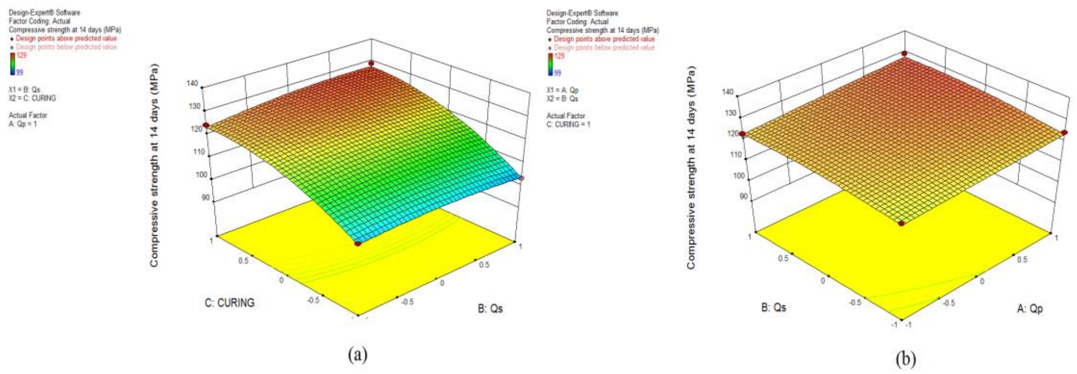


Fig. 5 Response surface of 14-day compressive strength

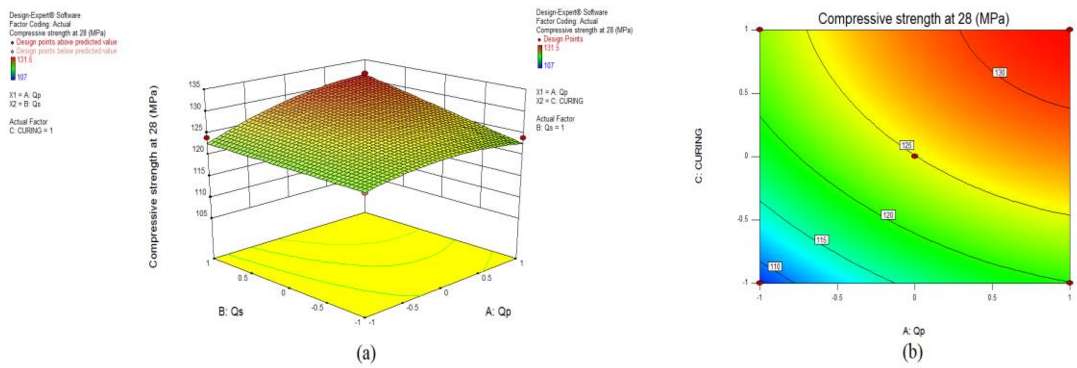


Fig. 6 Contour plot and response surface of 28-day compressive strength

be seen when all variables are in maximum level (1). It is concluded that these three variables play important roles on 7-day compressive strength.

Fig. 4 significantly illustrates the effect of curing on 7-day compressive strength increases, and also the possivite effect between quartz sand and quartz powder on 7-day compressive strength on 7-day compressive strength of UHPC.

4.2 Effect of variables on 14-day compressive strength

The effect of variables on 14-day compressive strength is monitored as 3D plot in Fig. 5. It clearly shows the positive effect of variables to increase the 14-day compressive strength as the Maximum value of 14-day compressive when variables are in the highest level of variables. 28% increasing on 14-day compressive strength of UHPC between lowest level of variables and maximum level of variables was obtained.

The effect of curing and quartz sand on 14-day compressive strength is illustrated in Fig. 5(a). Increasing the rate of curing temperature and substituting the quartz sand with crushed limestone aggregate raise the 14-day compressive strength of UHPC. As it is clear that thermal water curing significantly effects 14-day compressive strength. It is concluded that temperature water curing significantly effects on compressive strength of UHPC at early ages. Substituting of crushed sand stone by quartz sand has positive effect on 14-day compressive strength which is shown in Fig.

5(a).

The effect of Qp on 14 day compressive strength is given in Fig. 5(b). Substituting cement by quartz powder has positive effect on 14 day compressive strength.

4.3 Effect of variables on 28-day compressive strength

The effect of variables on 28-day compressive strength is shown in Fig. 6 as 3D plotting. It shows the positive effect of variables on 28-day compressive strength of UHPC as highest level (1) of variables together gives the maximum 28-day compressive strength.

The effect of quartz powder and quartz sand on 28 compressive strength is given in Fig. 6. It shows that by increasing quartz powder as cement substitution and limestone replacing by quartz sand, the 28-day compressive strength rate is increasing.

Two interaction of themal water curing regimes and quartz powder is shown in Fig. 6(b) which is concluded that by substituting the cement with quartz power and increasnig the water curing tempreature the compressive strength is mainly increased.

5. Conclusions

The effect of three controllable variables (Quartz powder, Quartz sand, different water curing temperature) on mechanical properties of UHPC with local materials were investigated by using central composition response surface methodology and quadratic models for responses were performed. In this experimental study, interaction and correlation of three variables were performed. The significance of model and factors were analyzed by ANOVA. The important findings are listed as follow:

Quadratic model with R2 of above 0.975 were obtained for 7, 14, and 28-day compressive strength. The result shows the variables did not have a main effect on 28-day splitting tensile strength despite, having R2 of 0.83 which is shown the accuracy of using ANOVA.

Increasing 7, 14, and 28-day compressive strength treatment of UHPC were occurred by replacing the quartz powder with cement which causes to decrease the cement consuming up to 20% and produce a more environmental friendly.

Substituting of crushed limestone sand by quartz sand is modifying the compressive strength treatment in different ages.

Change of Thermal water curing significantly influences 7, 14, and 28-day compressive strength of UHPC.

6. Conflict of interest

Conflict of Interest: The authors declare that they have no conflict of interest.

References

Aldahdooh, M.A.A., Bunnori, N.M. and Johari, M.M. (2013), “Evaluation of ultra-high-performance-fiber reinforced concrete binder content using the response surface method”, *Mater. Des.*, **52**, 957-965.

Ambily, P.S., Ravisankar, K., Umarani, C., Dattatreya, J.K. and Iyer, N.R. (2013), “Development of ultra-high-performance geopolymer concrete”, *Mag. Concrete Res.*, **66**(2), 82-89.

Arafa, M., Shihada, S. and Karmout, M. (2010), “Mechanical properties of ultra high performance concrete produced in the gaza strip”, *Asian J. Mater. Sci.*, **2**(1), 1-12.

De Larrard, F. and Sedran, T. (1994), “Optimization of ultra-high-performance concrete by the use of a packing model”, *Cement Concrete Res.*, **24**(6), 997-1009.

Kumar, V., Sondergeld, C.H. and Rai, C.S. (2012), “Nano to macro mechanical characterization of shale”, *Proceedings of the SPE Annual Technical Conference and Exhibition*, Society of Petroleum Engineers.

Mohammed, B.S., Abdullahi, M. and Hoong, C.K. (2014), “Statistical models for concrete containing wood chipping as partial replacement to fine aggregate”, *Constr. Build. Mater.*, **55**, 13-19.

Mosaberpanah, M.A. and Eren, O. (2016), “CO_2-full factorial optimization of an ultra-high performance concrete mix design”, *Eur. J. Environ. Civil Eng.*, 1-14.

Prem, P.R., Murthy, A.R. and Bharatkumar, B.H. (2015), *Influence of Curing Regime and Steel Fibres on the Mechanical Properties of UHPC*.

Reda, M.M., Shrive, N.G. and Gillott, J.E. (1999), “Microstructural investigation of innovative UHPC”, *Cement Concrete Res.*, **29**(3), 323-329.

Reddy, T.C.S. and Elumalai, J.K. (2014), *Study of Macro Mechanical Properties of Ultra High Strength Concrete Using Quartz Sand and Silica Fume*.

Richard, P. and Cheyrezy, M. (1995), “Composition of reactive powder concretes”, *Cement Concrete Res.*, **25**(7), 1501-1511.

Sahani, B.S. and Ray, N.H.S. (2014), “A comparative study of reactive powder concrete and ordinary Portland cement by ultra high strength technology”, *J. Res.*, **1**(6), 524-534.

Wang, D., Shi, C., Wu, Z., Xiao, J., Huang, Z. and Fang, Z. (2015), “A review on ultra high performance concrete: Part II. Hydration, microstructure and properties”, *Constr. Build. Mater.*, **96**, 368-377.

Wang, X.Y. (2014), “Properties prediction of ultra high performance concrete using blended cement hydration model”, *Constr. Build. Mater.*, **64**, 1-10.

Wille, K. and Boisvert-Cotulio, C. (2015), “Material efficiency in the design of ultra-high performance concrete”, *Constr. Build. Mater.*, **86**, 33-43.

Yazici, H. (2007), “The effect of curing conditions on compressive strength of ultra high strength concrete with high volume mineral admixtures”, *Build. Environ.*, **42**(5), 2083-2089.

Yu, R., Spiesz, P. and Brouwers, H.J.H. (2014), “Mix design and properties assessment of ultra-high performance fibre reinforced concrete (UHPFRC)”, *Cement Concrete Res.*, **56**, 29-39.

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