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)

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

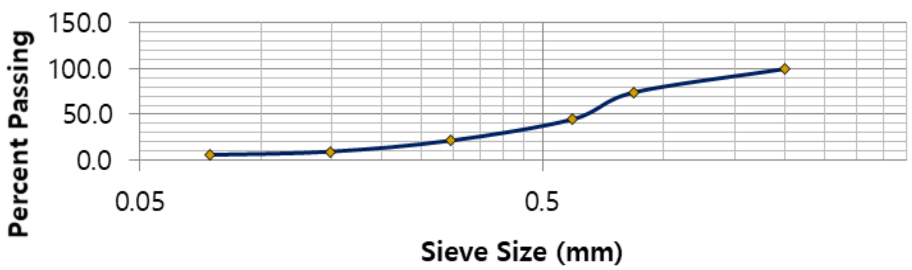


Fig. 2 Size distribution of crushed quartz sand

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 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

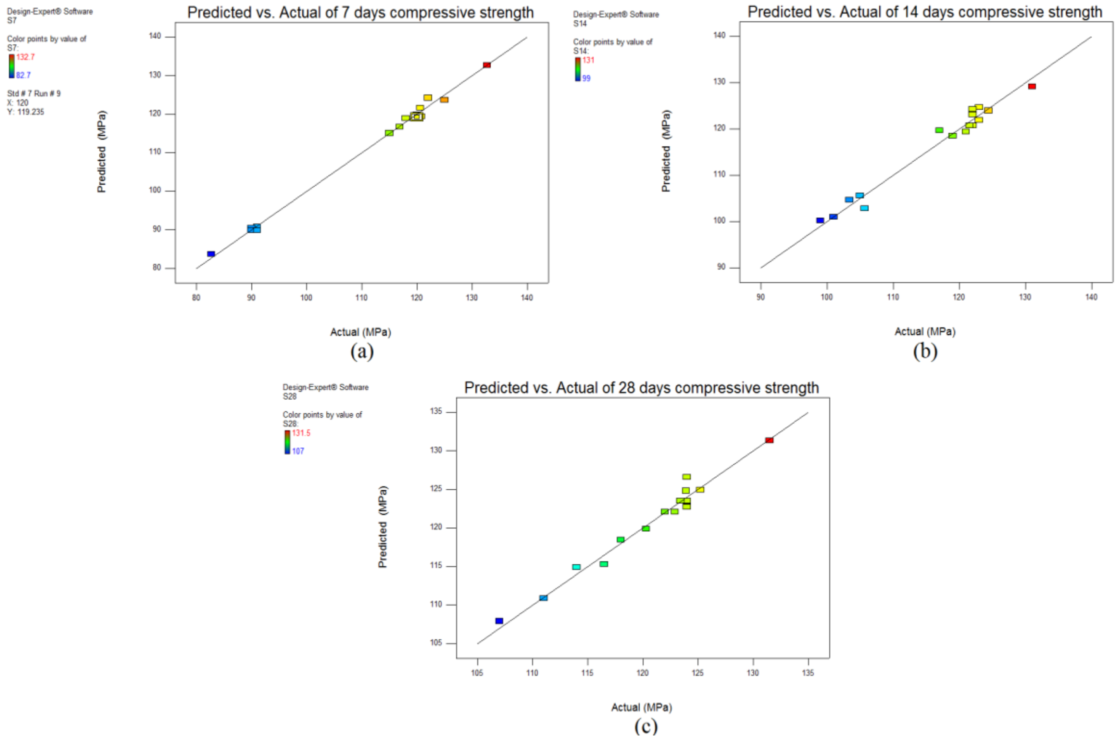
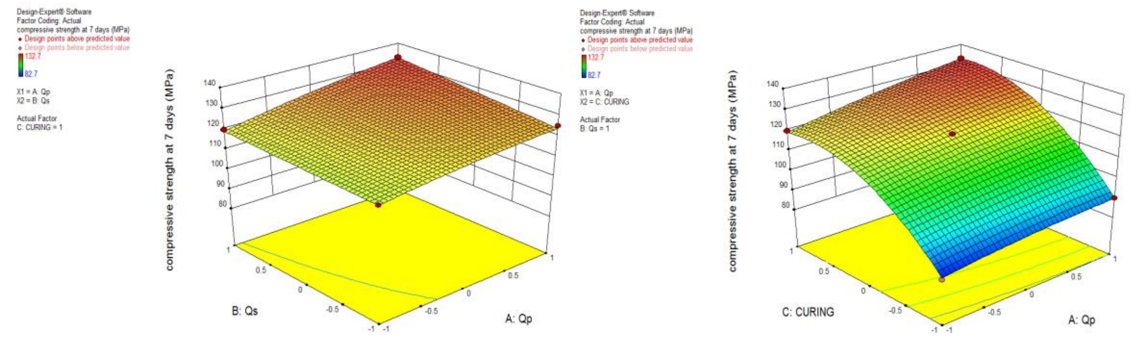


Fig. 3 Prediction of efficiency of offered model for 7, 14, 28-day compressive strength

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.



(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

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.

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