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Predicting Contour Slump Flow of Self-Compacting Concrete using Bentonite as Filler

Arabi N. S. Al Qadi[1]*, Madhar Haddad[2]

1. Department of Engineering, Ajloun National University, P.O. Box 43, 26810, Ajloun, Jordan.

2. Department of Architectural Engineering, United Arab Emirates University, P. O. Box 15551, Al Ain, UAE.

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Abstract: This research presents the application of the Box-Benken design method to develop a model for predicting contour slump flow and its desirability in self-compacting concrete (SCC) with partial replacement of cement with bentonite. The slump flow has been measured for 15 mixtures prepared at the laboratories of Al Hussien Bin Talal University and Ajloun National University. The use of Bentonite as filler materials in self-compacting concrete can add many benefits that are directly related to the workability and consistency of various cementitious materials, besides the fact that it is possible to reduce the quantities of cement and optimize the percentage in the composite. The performance of the model can be judged by the Correlation Coefficient (R^2), Mean Absolute Error (MAE) and Root Mean Square Error (MSE) which have been adopted as the comparative measures against the experimental results obtained from the mixtures, and found the best percentage of Mennonite in SCC.

Key words: Box-Benken method; Bentonite; Self-compacting concrete; Contour slump flow

1. Introduction

Self-compacted concrete (SCC) has been described as "the most revolutionary development in concrete construction for several decades" (EFNARC Specification and Guidelines for SCC.2002) [1].

Jordanian Bentonite which is a clay material is studied as filler in a set of SCC mixes and with different percentages to indicate its effect on hardened properties of SCC. Box-Behnken design of experiment approach is used along the way to analyzing, interpreting and modeling of the results. Bentonite is an absorbent of aluminum phyllo silicate minerals, essentially impure clay consisting mostly of montmorillonite. The absorbent clay was given the name bentonite by Wilbur C. Knight in 1898, after the Cretaceous Benton Shale near Rock River, Wyoming. Bentonite usually forms from weathering of volcanic ash, most often in the

Corresponding author: Arabi N. S. Al Qadi, Department of Engineering, Ajloun National University, P.O. Box 43, 26810, Ajloun, Jordan.

presence of water. However, the term bentonite, as well as similar clay called tonstein, has been used to describe clay beds of uncertain origin. For industrial purposes, two main classes of bentonite exist: sodium and calcium Bentonite (Hosterman [2]).

Al Qadi et al. [3] presented the application of design of experiment to predict model for 28 days compressive strength of SCC with replacement of cement with Wadi Musa bentonite, Jordan, for which the 15 mixtures have been tested. The use of Bentonite as filler in SCC can be directly related to the durability of various cementitious materials. The modified model can be examined by the correlation coefficient (R^2). Mean Absolute Error and root Mean Square Error were adopted as the comparative indications against the experimental results obtained from the mixtures indicate the good percentage of Bentonite in SCC. The developed SCC by using contrast constant factorial design to determine if adjustment of the four factors, viz: cement content (C), water to powder (w/p) ratio, fly ash (FA) content and super-plasticizer (SP), will increase the compressive strength of self-compacting concrete (SCC). It was concluded that to maximize the compressive strength, variables like cement content, water to powder ratio, fly ash content and super plasticizer dosage, should be kept at a high level, in which is relatively robust to content of super-plasticizer. The highest compressive strength is obtained when cement contents, w/p, fly ash (FA) contents are high and SP is low (Al Qadi et al. [4]).

Long et al. [5] modeled the effect of mixture parameters and material properties on the hardened properties of pre-stressed self-compacting concrete (SCC) and also investigated the extensions of the statistical models, in which a factorial design was employed to identify the relative significance of the primary parameters and their interactions in terms of the mechanical and visco-elastic properties of SCC. In addition to the 16 fractional factorial mixtures evaluated in the modeled region of −1 to +1, eight axial mixtures were prepared at extreme values of −2 and +2 with the other variables maintained at the central points. Four replicate central mixtures were also evaluated. The effects of five mixture parameters, including: binder type, binder content, dosage of viscosity modifying admixture (VMA), water-cementitious material ratio (w/cm) and sand-to-total aggregate ratio (S/A) on compressive strength, modulus of elasticity, as well as autogenous and drying shrinkage were discussed. The applications of the models to better understand trade-offs between mixture parameters and carry out comparisons among various responses were also highlighted. A logical design approach would be to use the existing model to predict the optimal design, and then run selected tests to quantify the influence of the new binder on the model. Fillers in general aim to enhance quality or lowering the cost of concrete mixes, such reasons made the engineering community look forward to discover new fillers that are reliable and efficient to be used, and thus it is important to support this field with research and development in order to produce SCC that can be used efficiently, safely and reliably.

The objective of this research is to study the workability, consistency and filling ability of the predicting contour slump flow of SCC with addition of Bentonite as filler.

2. Methodology

Material Used: Ordinary Portland cement available in the local market is used as cement in the current investigation. The cement used has been tested in various proportions as per ASTM C150-85A [6], in which the specific gravity and fineness were respectively found to be 3.15 and 2091 cm^2 gm-1. Crushed angular granite material of 2 cm max size, from a local source, with specific gravity of 2.45, absorption value was 2%, fineness modulus 6.05 and bulk density of 1480 kg per m^2, matching the specifications of ASTM C 33-86 [7]. Aggregate with maximum size of 0.475 cm, a modulus of fineness 4.16, a Specific gravity of 2.33 and absorption of 11% was used as a fine aggregate. Sodium Bentonite sample extracted from Wadi Mousa and sieved through sieve number 200 was used as bentonite. Table 1 shows chemical and physical properties. Polycarpoxylicether (PCE) super-plasticizer which is brown color having relative density 1.15 according to ASTM C 494-92 [8] standard was used as a super plasticizer. Finally, potable water was used according to ASTM D 11-29 standard.

Design of Experiment Approach: Design of Experiment (DOE) approach was used in this study. DOE offers lesser number of representative samples, the ability of analyzing and interpreting, controlling and organizing the research. Moreover, Box-Behnken method specifically was used is because it is convenient for engineering application (*Jmp software Manuel. version 12*) [9] for these reasons, the previous methods were selected to be used in the current research. In statistics, Box–Behnken design are experimental design for response of surface methodology, devised by George E. P. Box and Donald Behnken in 1960 [10], to achieve the following goals: Each factor variable is placed at one of three equally spaced values, usually coded as -1, 0, and +1. The design should be sufficient to fit a quadratic model that is one containing squared terms and products of two factors. The ratio of the number of experimental points to the number of coefficients in the quadratic model should be reasonable. The estimation variance should be more or less depend only on the distance from the center and should not vary too much inside the smallest (hyper) cube containing the experimental points. 15 mixes with different ratios for each were worked to fulfill the requirements of the design of experiment conducted.

Mixture Preparation: Each mix of these 15 mixes was subjected to hardened properties tests. Cubes were casted with material proportions for compressive strength test, and beam casted with material proportions if flexure strength were tested. Slump flow by Abrams cone was conducted to indicate the workability and consistency of the SCC mixes. ASTM C1611/C1611M [11] procedure was used for the slump flow test. The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan for use in assessment of high rise building and offshore concrete. The test method is based on the determining of the slump flow. The diameter of the concrete circle is a measure for the filling ability of the concrete to be conducted as shown in Table 1.

Table 1: Chemical and physical properties of Mennonite

Chemical Symbols (%)			Bentonite(%)
Na_2O	0.13	Specific gravity	2.60
MgO	3.50	Specific surface area (m^2/g)	410
Al_2O_3	20.1	CEC Meql100g	65
SiO_2	55.7	Oil absorption(%) by wt	80
K_2O	2.50	Water absorption(%) by wt	207
CaO	2.20	Attrition resistance %	90
TiO_2	2.54	Adsorption of water vapor %	13
Fe_2O_3	13.50	Bleaching capacity of edible oil (%)	89

3. Results and Discussion

The results listed in Table 2 were analyzed and interpreted in details and were subjected to statistical models in the light of Box-Behnken design of experiment.

Table 2: Mixtures proportions and slump flow of SCC

Mix No.	C (Kg/m^3)	W/P Ratio	B (%)	W (Kg/m^3)	S (Kg/m^3)	CA (Kg/m^3)	FA (Kg/m^3)	Slump flow (mm)
1	450	0.38	5	177	9	1042	669	485
2	400	0.45	20	216	8	971	623	650
3	350	0.45	12.5	177	7	1083	696	573
4	350	0.38	5	138	7	1164	747	480
5	450	0.30	20	152	9	1063	682	545
6	350	0.30	12.5	118	7	1179	757	565
7	400	0.45	5	189	8	1052	675	550
8	450	0.38	20	203	9	959	616	665
9	450	0.45	12.5	228	9	939	603	690
10	400	0.38	12.5	169	8	1066	684	450
11	400	0.38	12.5	169	8	1066	684	450
12	400	0.38	12.5	169	8	1066	684	450
13	400	0.30	20	144	8	1088	698	465
14	400	0.30	5	126	8	1154	741	445
15	350	0.38	20	158	7	1099	706	475

The slump flow diameter of each mix is considered as the average of three measurements. The response of each mixture for different proportions of bentonite; cement and w/p ratios is analyzed. The slump flows of each mixture show differences according to the material proportions. It is noticed that mixtures containing such as more powder showed better slump flows, such that more bentonite added with the powder content and a w/p reaching 0.5 can enhance the slump flow according to the nature and atmosphere of the experiment. Table 3 (a) and (b) show the summary effect in a regression output of full quadratic model for the responses of mixtures of the slump flow. Regression model of slump flow was developed, as presented by equation (1).

$$Slump\ flow = 45 + 2.25C + \frac{3.74W}{P} + 2.84B + 1.075C * \frac{W}{P} + 4.175C * B + \frac{1.75W}{P} * B + 5.83C^2 + 6.15\left(\frac{W}{P}\right)^2 + 1.35B^2 \quad (1)$$

Figure 1 shows the predicted slump flow vs the actual slump flow obtained for 5% Bentonite. The slump flow of mixes is examined and discussed for fresh property in detail for the purpose of examining the effect of bentonite on the slump flow of the mixtures.

Table 3: Regression output of full quadratic models for slump flow

		Estimates and sorted parameter terms					
Parameter	Estimate	Standard Error (SE)	t-Ratio	p-value	R^2 %	R^2 adj %	S
Slump flow					88.96	64.12	3.879
Intercept	45	2.425661	18.55	0.001*			
C(350,450)	2.25	1.485408	1.51	0.1903			
w/p(0.3,0.45)	3.74	1.485408	2.52	0.0534			
bennonite(0.05,0.2)	2.84	1.485408	1.91	0.1143			
C*w/p	1.075	2.100684	0.51	0.6306			
C*bentonite	4.175	2.100684	1.99	0.1036			
w/p*bentonite	1.75	2.100684	0.83	0.4428			
C*C	5.83	2.186462	2.66	0.0447*			
w/p * w/p	6.15	2.186462	2.81	0.0374*			
bentonite*bentonite	1.35	2.186462	0.62	0.5640			

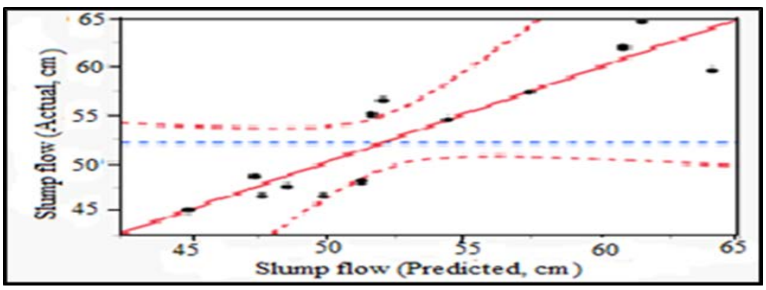


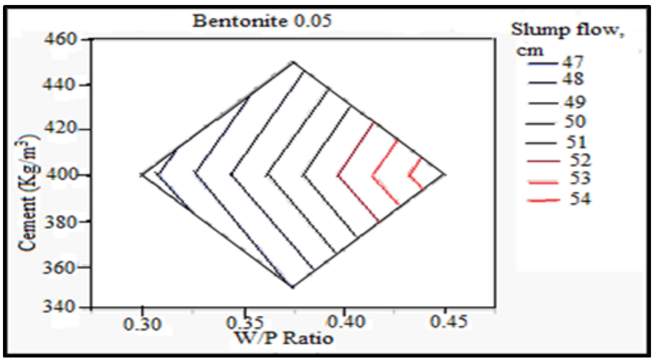
Figure 1: Plot of slump flow: actual versus predicted

Figure 2(a) red lines that represent a 54cm slump flow which is located at the right edge of the contour plot and cannot be maximized with this ratio of materials used. The best slump that can be obtained with 5% of bentonite is 540 mm, which contains a 400 kg/m^3 cement and 0.45w/p.

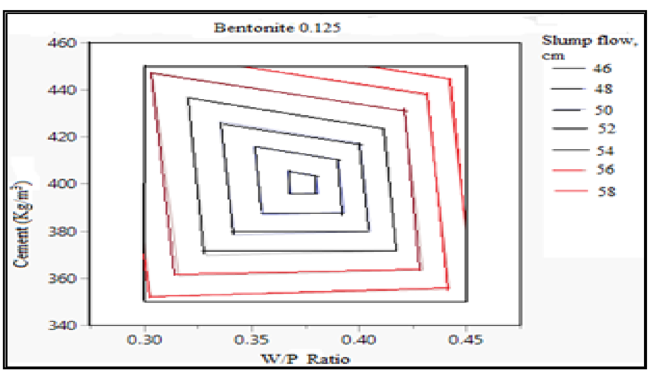
Figure 2(b) present the slump flows obtained when 12.5% of bentonite replaces cement, thus the mix contains (456 to 500 kg/m^3) of bentonite, (380 to 400 kg/m^3) of cement and (0.40 to 0.45) w/p. The mix according to the material proportions for the 12.5% bentonite mixes cannot have a slump flow higher than 580 mm, which is the maximum value of and represented by red lines and the reason may be due to the high viscosity.

Figure 2(c) shows that the slump flow is minimal at lower w/p ratios. It should be noted that w/p ratios cannot be increased due to technical consideration, instead of that using a viscosity modifying agent may produce better results. A 625 mm slump flow is obtained within the accepted range when 20% bentonite is used along with (410 to 440 kg/m^3) of cement and (0.38 to 0.45) w/p ratio. The contour plots from Figure 2 shows that the 20% of bentonite replacing cement is the best for obtaining higher slump flow and shows significant difference than mixes that contain lesser bentonite.

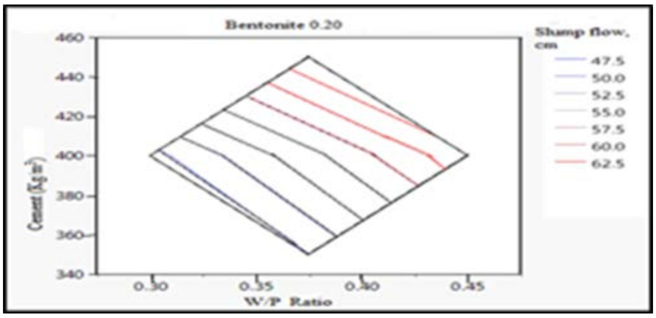
From Figure 2, it can be concluded that 20% of bentonite replacing cement is the best to obtain higher slump flow, which shows significant difference than mixes of lesser bentonite.



(a)



(b)



(c)

Figure 2: Contour plot of slump flow response (cm) at bentonite of (a) 5%, (b) 12.5 % and (c) 20%

Prediction profiler shown in Figure 3 based on the DOE predictions indicate that to reach a slump flow within the acceptable range or to maximizing the desirability by reaching 741.5 mm slump flow, it is recommended to use the following ratios: 450 kg/m^3 cement, 0.45 w/p ratio and a 20% of bentonite as a filler replacing cement. Results and findings that are less than the acceptable range can be due to the high viscosity or high yielding value according to the EFNARC (2000) guide. However, viscosity can be minimized by increasing the dose of the super plasticizer or by using a viscosity modifying agent (VMA).

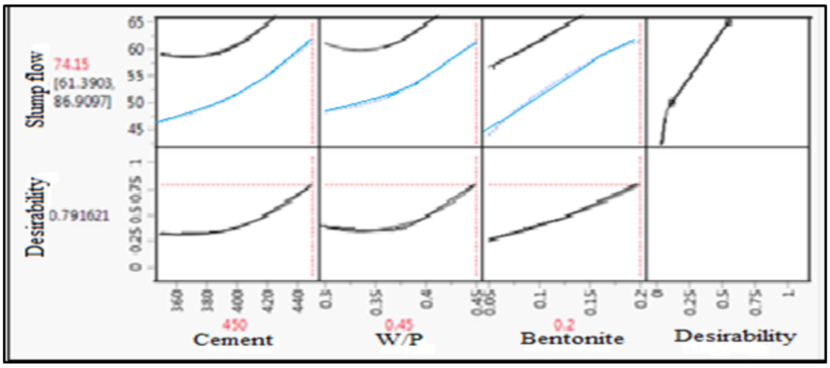


Figure 3: Prediction profiler of the effect of cement, w/p ratios and bentonite on the slump flow

4. Conclusion

It was concluded from this research that:

- Statistical models of the DOE for studying the effect of Bentonite replacing cement by weight from 5% to 20% can give a slump flow within the acceptable limits.
- Mixture 8 and 9, (450 kg/m^3 cement, 0.38 to 0.45 w/p ratio, 12.5% to 20% bentonite, 203 to 228 kg/m^3 water, 9 kg/m^3 SP, 959 to 939 kg/m^3 coarse aggregate, 616 to 603 kg/m^3 fine aggregate) which as predicted will give high workability, can be used for reinforced-concrete mixes that require a self-compacting concrete of grad M45.
- Prediction profiler, derived based on DOE predictions, indicates that to reach a slump flow within the acceptable range or to maximizing the desirability, the following ratios: 74.15 cm slump flow, 450 kg/m^3 cement.

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