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THE EFFECT OF ALUMINUM TRI-HYDRATE ON THE SLUMP TEST OF SELF-COMPACTING CONCRETE USING THE DESIGN OF EXPERIMENT METHOD

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Abstract

Concrete is a family of binding material, fine aggregate, coarse aggregate and water. Concrete is normally used in the frame structure. But there is some limitation like self-compaction, surface finishes, maintains strength at congested area. Due to this limitation making self-compacting concrete with the use of mineral admixture are considered in this research. SCC is a concrete that can be placed and compacted under its own weight without any vibration effort, assuring complete filling of formwork even when access is hindered by narrow gaps between reinforcement bars. The primary objective of this study is to make a design of experiment by Box Behnken design and response surface methodology, to add Aluminum Tri-hydrate (ATH) and understand its effects on fresh property. The result indicated that the described ATH% is -4.550 ± 0.01763 Slump flow (mm). Additionally, 45.0% of the variation in ATH is explained by Slump Flow.

Keywords: Self-Compacting Concrete; Aluminum Tri-hydrate; Box Behnken; Slump test; Compressive strength.

Introduction

Self‒compacting concrete is one of "the most revolutionary developments" in concrete research, this concrete is a family of binding material, fine aggregate, coarse aggregate and water. Concrete is normally used in the frame structure, but there is some limitation like self-compaction, surface finishes, maintains strength at a congested area. SCC is concrete that can be placed and compacted under its own weight without any vibration effort, assuring complete filling of formwork even when access is hindered by narrow gaps between reinforcement bars. Arabi Al Qadi et al. [1].

Aluminum tri-hydrate, also known as Aluminum Tri-hydroxide or Alumina Tri-hydrate is derived from Bauxite Ore. This natural ore is refined to a fine white powder via the Bayer process. After washing and drying it is used as the feedstock for a wide range of alumina chemicals. Tony and DPhil [2].

Al_2O_3 nano-particles with the average diameter of 15 mm were used with four different contents of 0.5%, 0.1%, 1.5% and 2.0% by weight. The results showed that the use of nano-Al_2O_3

particles up to maximum replacement level of 2.0% produces concrete with improved strength. However, the ultimate strength of concrete was gained at 1.0 weight % of cement replacement. The workability of fresh concrete was decreased by increasing the content of Al_2O_3 nano-particles. It is concluded that partial replacement of cement with Nano-phase Al_2O_3 particles improves the compressive strength of a concrete but decreases its workability. Akrochem Corporation [3]

Nan Su et al. [4] proposed a new mix design method for self-compacting concrete. First, the amount of aggregates required was determined, and the paste of binders was then filled into the voids of aggregates to ensure that the concrete thus obtained has flowability, self-compacting ability and other desired SCC properties. The number of aggregates, binders and mixing water, as well as type and dosage of super plasticizer to be used are the major factors influencing the properties of SCC. Slump flow, V-funnel, L-flow, U-box and compressive strength tests were carried out to examine the performance of SCC, and the results indicated that the proposed method could be used to produce successfully SCC of high quality. Compared to the method developed by the Japanese Ready-Mixed Concrete Association (JRMCA), this method is simpler, easier for implementation and less time-consuming, requires a smaller amount of binders and saves cost.

Bouzoubaa and Lachemi [5] carried out an experimental investigation to evaluate the performance of SCC made with high volumes of fly ash. Nine SCC mixtures and one control concrete were made during the study. The content of the cementations materials was maintained constant 400 kg/m^3, while the water to cementations material ratios ranged from 0.35 to 0.45. The self-compacting mixtures had a cement replacement of 40%, 50%, and 60% by Class F fly ash. Tests were carried out on all mixtures to obtain the properties of fresh concrete in terms of viscosity and stability. They reported that economical SCC mixes could be successfully developed by incorporating high volumes of Class F fly ash.

Girish et al. [6] presented the results of an experimental investigation carried out to find out the influence of paste and powder content on self-compacting concrete mixtures. Tests were conducted on 63 mixes with water content varying from 175 l /m^3 to 210 l /m^3 with three different paste contents. Slump flow, V funnel and J-ring tests were carried out to examine the performance of SCC. The results indicated that the flow properties of SCC increased with an increase in the paste volume. As the powder content of SCC increased, the slump flow of fresh SCC increased almost linearly and in a significant manner. They concluded that paste plays an important role in the flow properties of fresh SCC in addition to water content. The passing ability as indicated by J-ring improved as the paste content increased.

Vanjare and Mahure [7] carried out an experimental study to focus on the possibility of using waste material in the preparation of innovative concrete. One kind of waste was identified: Glass Powder (GP). The use of this waste (GP) was proposed in different percentage as an instead of cement for the production of self-compacting concrete. The addition of glass powder in SCC mixes reduces the self-compatibility characteristics like filling ability, passing ability and segregation resistance. The flow value decreases by an average of 1.3%, 2.5% and 5.36% for glass powder replacements of 5%, 10% and 15% respectively.

Felekoglu et al. [8], has done research on effect of w/c ratio on the fresh and hardened properties of SCC. According to the author adjustment of w/c ratio and super plasticizer dosage is one of the key properties in proportioning of SCC mixtures. In this research, fine mixtures with different combinations of w/c ratio and super plasticizer dosage levels were investigated. The results of this research show that the optimum w/c ratio for producing SCC is in the range of 0.84-1.07 by volume. The ratio above and below this range may cause blocking or segregation of the mixture.

Nagataki and Fujiwara [9] performed the slump flow test of SCC mix to find out whether the concrete mix is workable or not. They also performed the segregation test of SCC mix, by using locally available materials, the value ranging from 500-700 mm is considered as the slump required for concrete to be self-compacted.

The primary objective of this research is to use aluminum tri-hydrate as additives on fresh properties of Self-Compacting Concrete (SCC). The study also intended to quantify the amount of aluminum tri-hydrate to be added to the concrete according to the value of concrete properties measured; using Box Benken Design of Experiment Method.

The Methodology of the research

Materials used

Ordinary Portland cement was used with specific gravity is 3.15. Locally available natural sand with 4.75 mm maximum size was used as fine aggregate, with specific gravity 2.66 , fineness modulus 2.32 ,bulk density 1780 kg/m^3 and absorption value 6.4% crushed stone with 16 mm maximum size used as coarse aggregate with specific gravity 2.67 , fineness modulus 6.86 ,bulk density 1540 kg/m^3 and absorption value 1.5% .Aluminum hydroxide is used as cement filer material with specific gravity 2.42. Potable tap water conforming to BS 3148 (1981) used for mixing and curing; Super-plasticizer used was Dynamon BT4 is a liquid super-plasticizing admixture for quality concrete (waterproof, durable and high strength) with a reduced loss in workability. Volume of Dynamon BT4 super-plasticizer from 0.5 to 1.5 liter per 100 kg of cement with density according to ISO 758 (g/cm^3) 1.06 ± 0.02 at +20°C [1] .

Experimental design

Box-Behnken designs method for developing a mathematical model used to find combinations of factors that yield optimal business performance. Box-Behnken designs are a type of response surface method, which provides detailed information about the solution space, allowing researchers to better understand the forces affecting the output of the model. Aslan, and Cebaci [10] Box –Behnken design to be the design method because of many advantages compared other response surface design: Box-Behnken designs usually have fewer design points than central composite designs, thus, they are less expensive to run with the same number of factors. Box-

Behnken designs do not have axial points, thus, it needs to a sure that all design points fall within safe operating zone and all factors are not set at their high levels at the same time.

Experimental design is widely used for controlling the effects of parameters in many processes. Its usage decreases the number of experiments, using time and material resources. Furthermore, the analysis performed on the results is easily realized and experimental errors are minimized. Statistical methods measures the effects of change in operating variables and their mutual interactions on process through experimental design way. Aslan, and Cebaci [10]

Box-Behnken designs have treatment combinations that are at the midpoints of the edges of the experimental space and require at least three continuous factors. The Box–Behnken experimental design was chosen for finding out the relationship between cement and water to powder and aluminum trihydrate and their effect on self-compacting concrete. Table 1 shows the coded values for Box-Behnken Design (BBD). Assign identifiers A (cement), B (W/P) and C (ATH) to each of the three variables were chosen with the low (-) and high (+) level for each factor then calculated the coded factor level by using Minitab. Table 2 indicates the coded factor levels.

The number of experiments (*N*) required for the development of BBD is defined as $N=2k\ (k-1) + C_0$, (where k is number of factors and C_0 is the number of central points)[7].

Results and Discussion

Fresh Properties of SCC

After mixing all materials of concrete they should work as fresh properties tests through 18 min in order to the percentage existence of water evaporation in concrete; then tested and studied their effects on characteristics of concrete depending on filling ability and passing ability. Slump flow test results for each mix two slump flow diameter were measured by using tape at two edges circular plate then the average is recorded and typical range of values (455-810) mm also, the time of the concrete that pass the 500mm distance till the concrete stop is recorded these are considered and acceptable according to the European guidelines (2000) for SCC.

MIX DESIGN

This term can be defined as the collection of the processes chosen the right material of concrete and calculated the proportion of ingredients of this concrete. Furthermore, there are calculations of total volume of cubes and prisms, three samples for each mix. Table 3 of mix design for ingredients of concrete required, the table divided into two parts (Volumetric Composition (m^3), Weight (Kg).

To analyze test results of slump flow see Table 3 that shows the basic relation between slump flows versus percent of ATH were noted; when the ATH increases the slump flow increases (positive relationship).

T_{500} test

The slump flow time is the period between the moment the cone leaves the base plate and SCC first touches the circle of diameter 500 mm. T_{500} is expressed in seconds to the nearest 1/10 seconds.

Minitab software

The study was carried out according to a BBD. Essentially, in finding a model that describes the relationship between the vital factors and the response, There are some graphs were could be shown these relationship factors and the response, There are some figures 1, 2, and 3 were could be shown these relationship.

Minitab's surface plots to be helped in visualizing the effects of continuous variables. Figure 1 shows how a response variable relates to two continuous variables based on a model equation while any additional variables are held constant. These plots are useful for establishing desirable response values and operating conditions. It can maximize the slump flow by cement (kg/m^3) near the minimum setting ($300kg/m^3$) and water over powder near the maximum setting (0.36).These settings, Slump flow is from 550mm to 600mm increase rapidly if it increase cement content while to hold temperature constant. Slump flow also decreases rapidly if it holed cement constant as by increasing w/p.

The surface plot also shows the effects in both Cement and w/p. That is, the response surface exhibits curvature as changed either variable while holding the other constant. The shape of this surface is known as a rising ridge.

Minitab's contour plot in Figure 2 is used to help visualize the effects of continuous variables. This Figure shows how a response variable relates to two continuous factors. For the cleaning Slump flow data, previous analysis showed that pressure cement and w/p have model effects on Slump flow, while ATH and SP only has a model effect.

Therefore, it makes sense to hold ATH and SP fixed at its low and high levels and compares the plots. Figure 2 shows how Cement and w/p were related to Slump flow when ATH is at its low level of 4%. The darkest green area indicates the contour where the response is the highest (550). To maximize Slump flow, it would be chosen Cement and w/p in the center of the right side of the plot.

Furthermore, cement around $500kg/m^3$ and a w/p around 0.32.Figure 2 shows how cement and w/p were related to slump flow when ATH is at its high level of 6%. The darkest green area indicates the contour where the response is the highest (500). To maximize Slump flow, it would choose settings for cement and w/p in the center of the right side of the plot. It was chosen cement around 500 and a w/p around 4.5. The plots indicate that as ATH increases from its low to high level (4% to 6%), slump flow also increases. The maximum slump flow of approximately 550 occurs around cement = 500, w/p = 0.32, and ATH = 6%.

Regression Analysis

Using Fitted line plot regression in Figure 3 represent the relationship between a predictor(X) and response(y) in order to check models fits of the data. This method performs regression with linear and polynomial. Table 4 shows the coded value for materials.
A linear model can show a steady rate of increase or decrease in the data. A quadratic model can account for curvature in the data. A cubic model may describe a "peak-and valley" pattern in the data. The relationship between factors and its existence in Table 4 show the effect of these. The general Formula for linear regression equation $Y = bo + b_1X$, where y (response variable), X(predictor variable), bo (intercept)and b_1(slope).Figure 3 shows the fitted regression for ATH and slump test.

The result indicated that the best fitting line is described by the fitted linear regression equation (1) is:

$$\text{ATH\%} = -4.550 + 0.01763 \text{ Slump flow (mm)} \quad (1)$$

The S is -4.550 ATH. Additionally, 45.0% of the variation in ATH is explained by Slump Flow. The adjusted R is 41.0%. This mean that the change in y occurs when x increases and the intercept bo=-4.550 is constant that determines the vertical placement of the regression line, S & R^2 indicated to how well the model fits the data.

Conclusions

After mixing 16 mixes each with different proportion, those mixes and their proportion were selected according to the European guidelines of SCC and Box-Behnken DOE was chose for controlling, analyzing, mixes, after that each mix were subjected to fresh properties tests, Results have been analyzed and studied and the following has been concluded.

- Requirements of filling ability, passing ability and segregation are fulfilled and within accepted ranges, thus using ATH as a filler with the specified mix proportions produced a SCC and according to the European guidelines for SCC a concrete mix can only be classified as self-compacting concrete if the requirements for all three characteristics are fulfilled
- The result indicated that the best fitting line is described by the fitted line of regression equation is:

  $$\text{ATH\%} = -4.550 + 0.01763 \text{ Slump flow (mm)}$$

  The S is -4.550 ATH. Additionally, 45.0% of the variation in ATH is explained by Slump Flow. The adjusted R is 41.0%.
- The slump flow is increase with the increase in cement content and increase as the w/p reduced.

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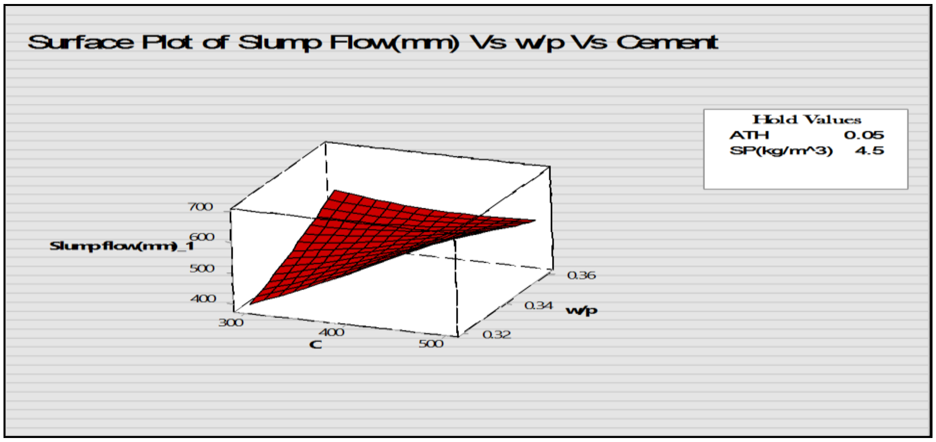

Figure 1: Surface Plot Vs slump flow for a Function of cement and w/p

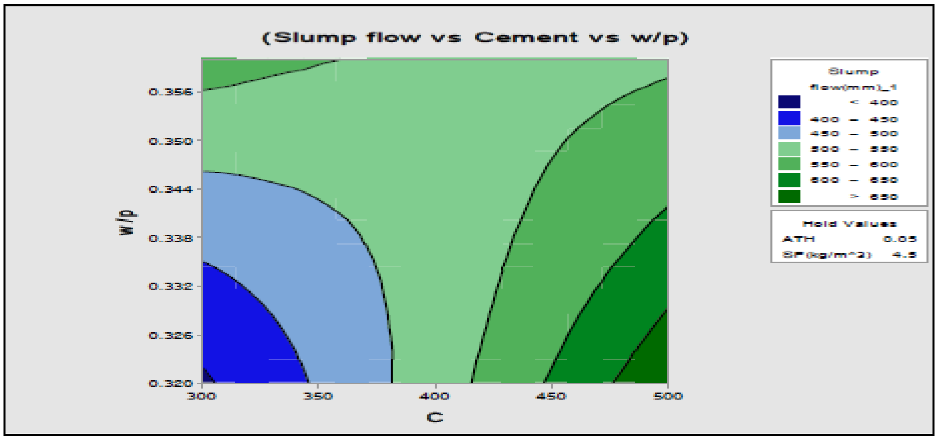

Figure 2: Contour plot Vs slump flow for as a Function of Cement and w/p

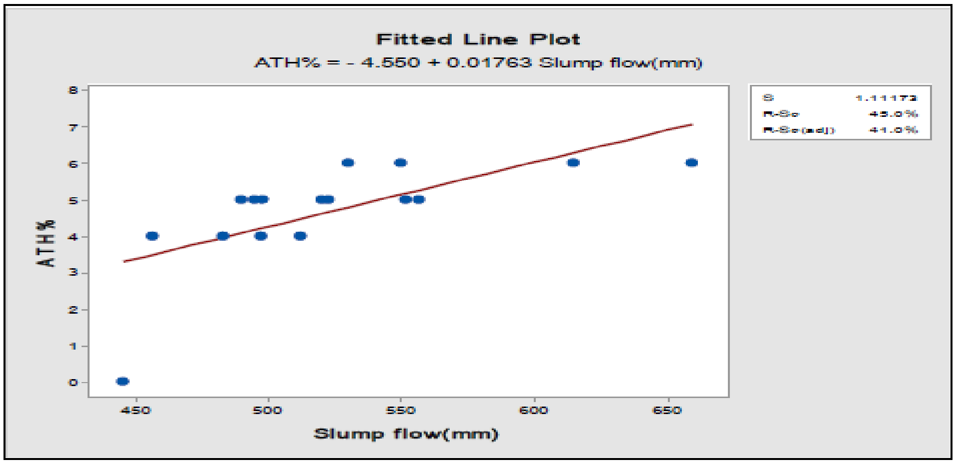

Figure 3: Fitted Line Plot Regression (ATH VS Slump Flow)

Table 1: Coded value of materials chosen for Box-Behnken design

Variable	Min -1	Center 0	Max 1
C	200	400	600
w/p	0.3	0.4	0.5
AL	0.03	0.055	0.08
Sp	3	6	9

Note: the amount of sp= 1.5% of the amount of cement

Table 2**:** Coded factor levels for a Box-Behnken design of a three-variable system

Experiment	A	B	C
1	0	0	0
2	1	0	0
3	1	-1	0
4	1	1	0
5	0	-1	1
6	0	-1	-1
7	0	0	0
8	-1	-1	0
9	-1	1	0
10	1	-1	1
11	0	0	-1
12	-1	0	-1
13	0	0	0
14	-1	0	1
15	0	1	1

Table 3: values of mix design ingredient as a volumetric composition (m^3)

C	W/P	ATH	Vw	Vc	Vca	Vfa	Val	Vsp	Vair	T_{500} (sec)	Slump test(mm)
500	0.36	0.05	0.18	0.159	0.3744	0.2496	0.0107	0.0065	0.02	0.5	552
400	0.32	0.04	0.128	0.127	0.4277	0.2852	0.0069	0.0052	0.02	1.22	456
500	0.34	0.04	0.17	0.159	0.3815	0.2543	0.0086	0.0065	0.02	1.4	497
300	0.32	0.05	0.096	0.0952	0.4671	0.3113	0.0065	0.0039	0.02	1.53	557
300	0.34	0.06	0.102	0.0952	0.463	0.3018	0.0078	0.0039	0.02	1.34	530
400	0.34	0.05	0.136	0.127	0.422	0.2810	0.0086	0.0052	0.02	1.05	490
400	0.32	0.06	0.128	0.127	0.4312	0.2870	0.0010	0.0052	0.02	1.06	550
300	0.34	0.04	0.102	0.0952	0.464	0.3090	0.0052	0.0039	0.02	0.99	483
400	0.34	0.05	0.136	0.127	0.422	0.2810	0.0086	0.0052	0.02	0.96	495
400	0.34	0.05	0.136	0.127	0.422	0.2810	0.0086	0.0052	0.02	0.97	498
400	0.36	0.06	0.144	0.127	0.422	0.2810	0.0010	0.0052	0.02	0.91	660
400	0.36	0.04	0.144	0.127	0.418	0.2780	0/0069	0.0052	0.02	1.02	512
500	0.34	0.06	0.17	0.159	0.379	0.2530	0.0129	0.0065	0.02	0.77	615
500	0.32	0.05	0.16	0.159	0.386	0.2570	0.0108	0.0065	0.02	0.70	523
300	0.36	0.05	0.108	0.0952	0.456	0.3100	0.0065	0.0039	0.02	0.69	520

Table 4: Coded value for materials

code	-1	0	1
C	300	400	500
W/P	0.32	0.34	0.36
AL	0.04	0.05	0.06
SP	4.5	6	7.5
Note: The amount of SP=1.5% of the amount of cement			