Using Design of Experiment to Predict Concert Compressive Strength Using Fly Ash and GGBFS as Cement Alternative

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Abstract

Many researches were done to replace portion of cement with other materials such as Fly Ash (FA) and Ground Granulated Blast Furnace Slag GGBFS using different ratios. In this research we used the Design of Experiment (DOE) method to come up with a mathematical equation that can be used to predict the compressive strength of Fly Ash and GGBFS Concrete on 7, 14, 28 days. This method is used to find and determine the effect of a factor on the output or final result of a process. Fly Ash is a by-product of coal-fired electric generating plants, while is a by-product of steel production process in blast furnaces.

Keywords
Design of Experiment, Fly Ash and GGBFS

1. Introduction

The manufacturing process of cement emits huge amount of Carbon dioxide (CO2) one of greenhouse gases which have a negative impact to the environment. Cement production contribute to around 5% of CO2 emissions worldwide. Many researches were done to replace portion of cement with other materials such as Fly Ash (FA) and Ground Granulated Blast Furnace Slag GGBFS using different ratios. In this research we used the Design of Experiment (DOE) method to come up with a mathematical equation that can be used to predict the compressive strength of Fly Ash and GGBFS Concrete on 7, 14, 28 days. This method is used to find and determine the effect of a factor on the output or final result of a process. Fly Ash is a by-product of coal-fired electric generating plants, while is a by-product of steel production process in blast furnaces. Replacing a portion of the cement with these materials will decrease the cement content in the concrete which will reduce the cost and environmental pollution.

2. Literature Review

Several researches were done to test the compressive strength on the concert mix using Fly Ash and GGBFS , to the best of our knowledge none of them used Design of Experiment to come up with a mathematical equation to predict the compressive strength of the concrete with various ratios of cement, fly ash and GGBFS. Harrison, et. al. (2014) did detailed experimental investigation on the acid resistance of ternary blended concrete immersed up to 32 weeks in sulphuric acid (H2SO4) and hydrochloric acid

(HCl) solutions. Arivalagan. S (2014), conducted a research study on the environmental benefit with fly-ash stated that there is increases in crop yields and nutrient uptake due to release of major secondary and micro nutrients from fly-ash applied in the soil during crop growth. Mahesh Patel (2013) described the feasibility of using the thermal industry waste in concrete production as partial replacement of cement. The use of fly-ash in concrete formulations as a supplementary cementitious material was tested as an alternative to traditional concrete. Tamilarasan V.S (2012)," study is mainly confined to evaluation of changes in both compressive strength and weight reduced in five different mixes of M30 Grade namely conventional aggregate concrete (CAC), concrete made by replacing 20% of Cement by fly-ash(FAC1), concrete made by replacing 40% of cement by fly ash(FAC2), concrete made by replacing 20% replacement of cement by GGBFS (GAC1) and concrete made by replacing 40% replacement of cement by (GAC2). Anand Kumar (2012*)* conducted a peculiar study on the utilization of materials which can fulfill the expectations of the construction industry in different areas. In his study cement has been replaced by fly-ash accordingly in the range of 0%,10%,20%,30%,40%,50%,60%by weight of cement for M-25 mix with 0.46 water cement ratio. Concrete mixtures were produced, tested and compared in terms of compressive strength. It was observed that 20% of replacement of Portland pozzolana cement (PPC) by fly-ash strength is increased marginally (1.9% to 3.2%) at 28 days and 56 days respectively.

3. Purpose of Research

The main purpose of this research paper is to use materials that are available in the market of Saudi Arabia to try to reduce the amount of cement in making concrete, which will reduce the bad impact on the environment.

4. Expected Outcome and design Mix

To develop a methodology of measuring the effect of using FA and on concrete properties using the design of experiment approach. Mix design was done on the right proportions and proper texture of concrete to be acceptable. The Mix design was done using an online calculation page (http://concrete.union.edu/WtSINon.htm) by adding all the needed input to get the proportions of the desired mix. All the input for the mix design process and result can be found in *(appendix A). The summary of the ingredients and cement replacement of the mixes can be found in the table 1:*

Table 1, Material concentrations with deferent mix

Mix Number	Material Concentraion in Cement		Amount of Material (kg)		
	FA	GGBS	Cement	Fly Ash	GGBS
Mix 1	50%	50%	7.67	3.83	3.83
Mix 2	50%	25%	9.58	3.83	1.92
Mix 3	25%	50%	9.58	1.92	3.83
Mix 4	25%	25%	11.50	1.92	1.92
Mix 5	0%	0%	15.34	0.00	0.00

The quantity needed to produce the needed amount of concrete for each mix was determined after calculating the volume and approximate weight of the need amount of concrete for the mix after adding 10% to compensate of wasted material. By assuming the concrete density to be 2375 kh/m^3, 87 kg of concrete will make 0.0366m3 which can fil 6 standard cylindrical molds.

5. Result and Discussions:

Analysis approach used for this study was Design of Experiment (DOE) which is a statistical tool used to find and determine the effect of factors and the relation between them on the

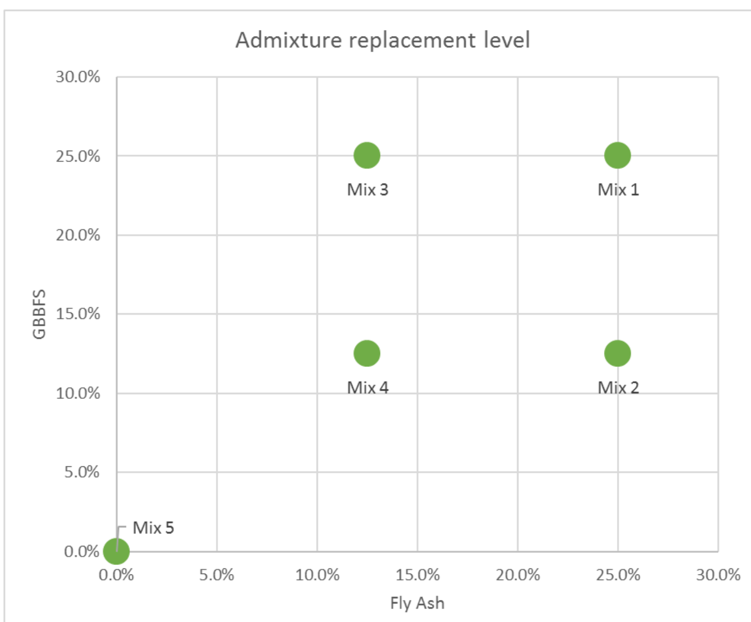

Figure 1, Admixture replacement level

output or final result of a process. This experiment sets both Fly Ash (Factor 1) and GGBFS (Factor2) as process factors using two levels of variation to come up a with a DOX test model. The levels of the factors in the model are represented by the percentage of admixture replacement of cement in the mix process. These percentages are set to (LOW=12.5%, HIGH=25%) for both Fly Ash and GBBSF. In the DoE, each level in a factor is tested with all the level of the second factor. This will yield 4 different samples of binder with different concentration of the FA and GBBFS. Beside a normal mix of 100% cement which was prepared to compare the result of the process with a base mix, 5 different concrete mixes were required for this experiment. The following chart shows the percent of admixture replacement of cement for both factors:

4. The results:

A compressive test was carried out on each mix on 7, 14, and 28 days which came out as follows:

Table 2, Compressive results with deferent mix

Mix Number	Material Concentraion in Cement		CompresiveTest (MPa)			Tempreture (C)
	FA	GGBS	7 Days	14 Days	28 Days	
Mix 1	25.0%	25.0%	11.74	14.72	19.54	27.3
Mix 2	25.0%	12.5%	10.85	13.65	18.33	27.7
Mix 3	12.5%	25.0%	12.16	15.38	15.93	26.8
Mix 4	12.5%	12.5%	10.61	13.24	16.84	27.9
Mix 5	0.0%	0.0%	10.18	12.22	14.84	27.1

5. Analysis:

The Analysis process was done through "Minitab" statistical analysis computer software. Using the different factor levels data (% cement replacement) alongside the result of the compressive strength test for the 4 tested mixes, DOE analysis compares the variance of the means between the different levels to generate an equation that define the expected outcome or the result of the process (compressive strength on 7,14, or 28 days).

The equation produced by the analysis shows the contribution of each factor to the process as well as the effect of having both factors in the process together. Factor contribution is represented in the coefficient of its terms in the equation. A graph can be developed to represent the equation in a way that shows an approximate prediction result of mixing different values of the two factors. Therefore, by using this graph it is possible to predict the compressive strength of mixing different proportions of Fly Ash or . Another use of the graph is to determine the

proportions of the tow admixture to achieve a desired compressive strength of the concrete, which is the ultimate goal of this experiment.

The DOE analysis result for the different testing days (7, 14, and 28) came as follows:

(Note: FlyAsh is factor A, and is factor B)

5.1 Strength on 7 Days (MPa):

This equation can be used to predict the strength of concrete for 7 days in (MPa):

Strength 7 (MPa) = 8.17 + 7.2 A + 17.6 B - 42.0 A*B

The effect of each factor on the strength:

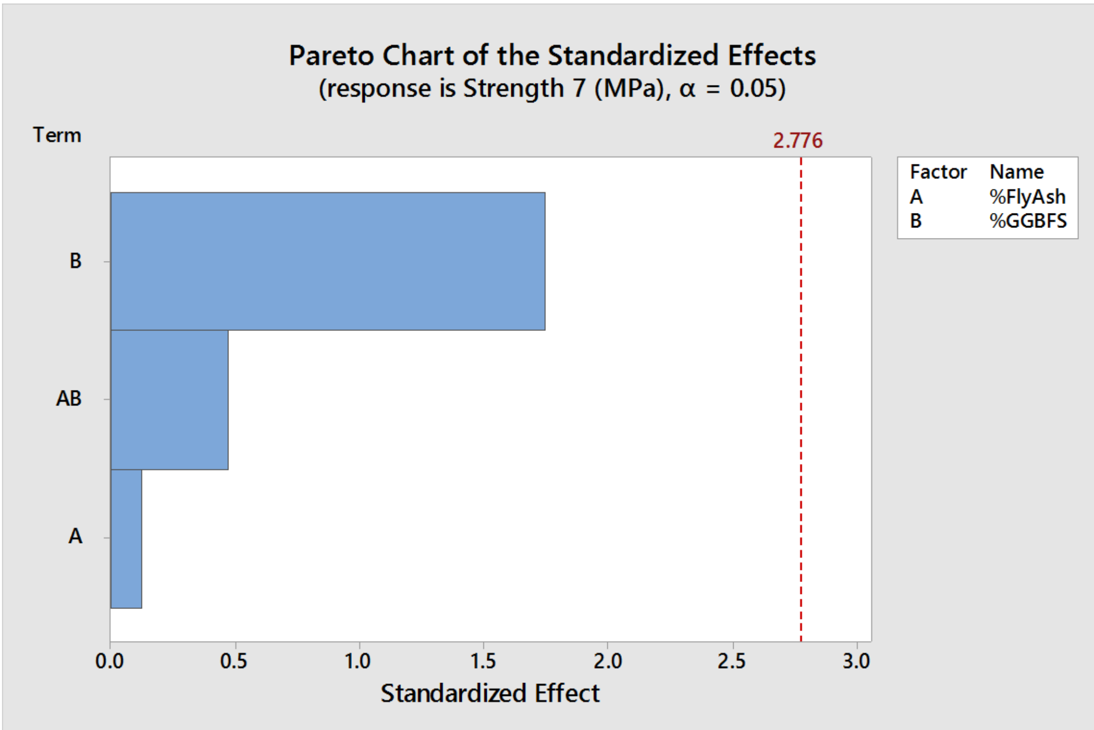

Figure 2, Pareto Chart with standardized effects

Graph shows Strength with respect to interaction between the 2 factors:

- *Strength is determined depending on the intensity of the color as shown in the legend.*

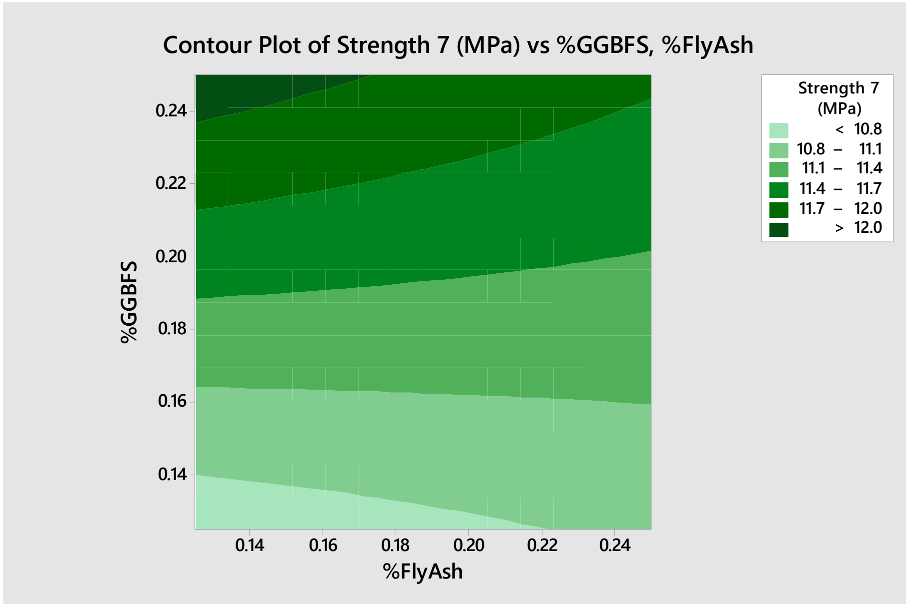

Figure 3, Contour plot of strength

5.2 Strength on 14 Days (MPa):

This equation can be used to predict the strength of concrete for 14 days in (MPa):
Strength 14 (MPa) = 9.63 + 11.9 A + 25.6 B - 69 A*B
The effect of each factor on the strength:

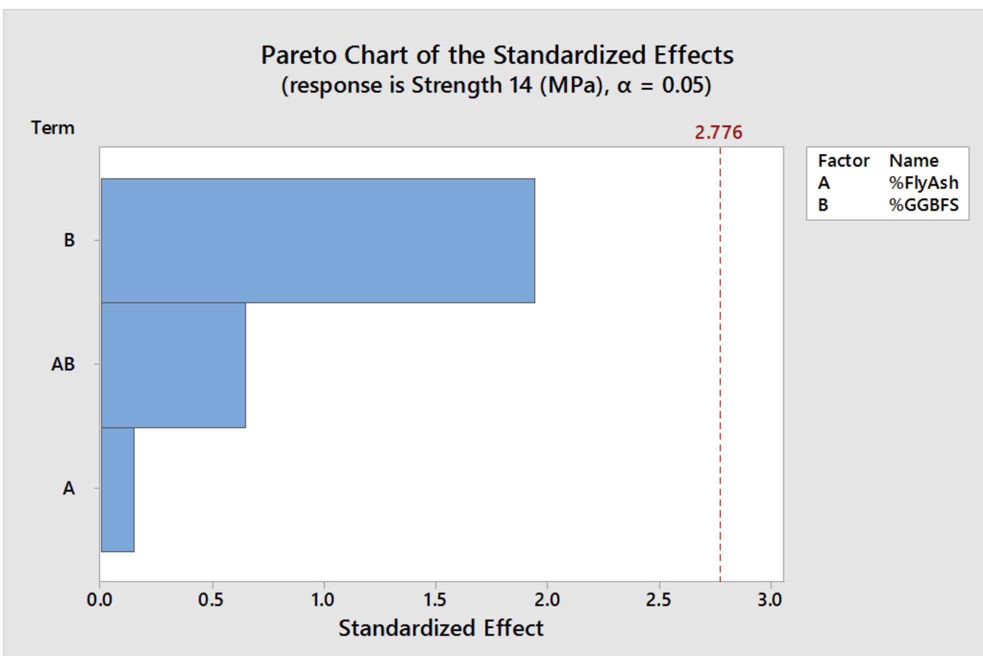

Figure 4, Pareto Chart with standardized effects

Graph shows Strength with respect to interaction between the 2 factors:

- *Strength is determined depending on the intensity of the color as shown in the legend.*

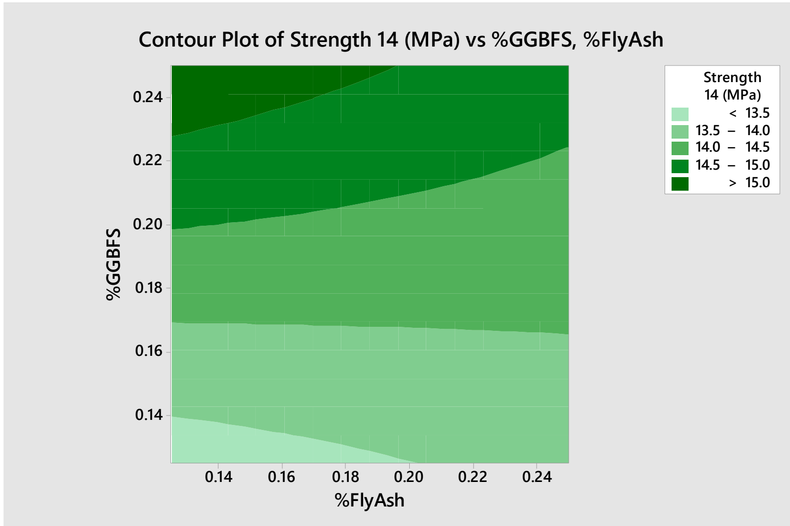

Figure 5, Contour plot of strength

5.3 Strength on 28 Days (MPa):
This equation can be used to predict the strength of concrete for 28 days in (MPa):
Strength 28 (MPa) = 18.35 + 4.9 A + 24.1 B - 135 A*B
The effect of each factor on the strength:

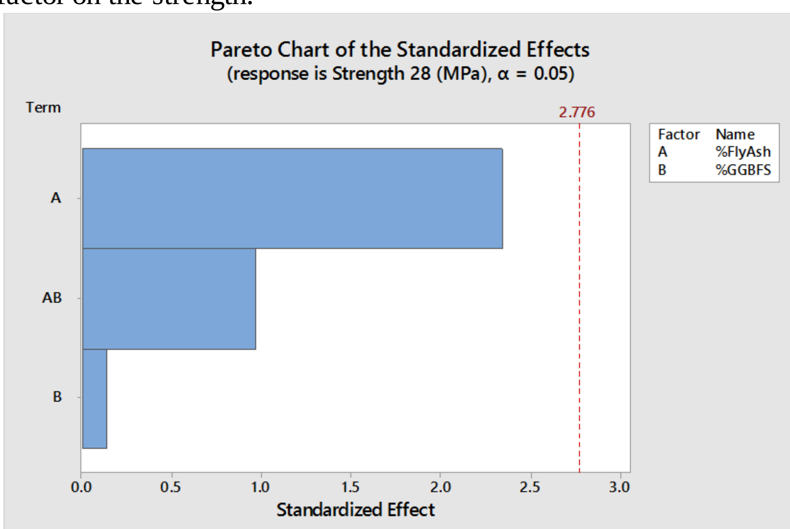

Figure 6, Pareto Chart with standardized effects

Graph shows Strength with respect to interaction between the 2 factors:

- *Strength is determined depending on the intensity of the color as shown in the legend.*

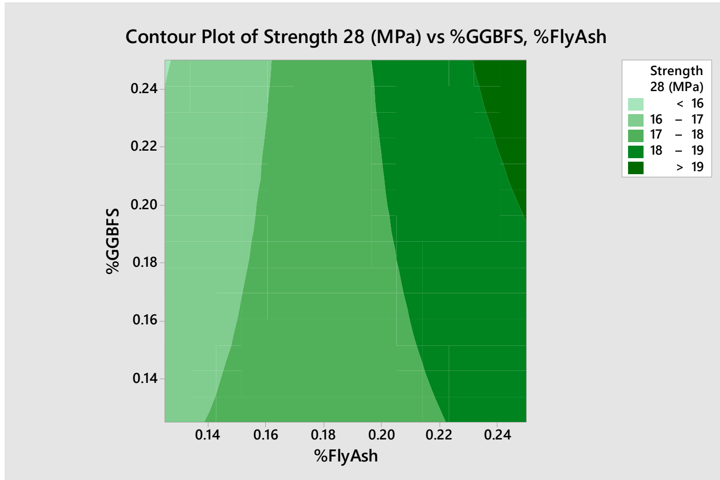

Figure 7, Contour plot of strength

6. Discussion:

The analysis results show that the is the main contributor to the compressive strength for the 7-day and 14-day tests, but the Fly Ash become the main contributing factor after 28 days. It means that the GBBFS provide strength at early at the beginning of the curing process, but the Fly Ash provide a big increase in strength on the long run. Also, it is noticeable that the coefficient of the term AB is relatively small, which means that the interaction between the materials is low and each factor can be considered to be working independently from one another.

The testing results in general shows some variation due to errors in the mixing and curing process. These errors affected the result of the design of experiment analysis. However, the methodology and approach of using DOE to find the relation and effects of multiple cement replacement admixtures on the compressive strength defiantly add a significant value to the study of admixture by introducing a new approach to study the effects. By applying the methodology on a larger number of samples for multiple levels of concentration of Fly Ash and GBBFS, a more precise equation for the compressive strength and other properties can be found, hence developing a reliable design model used for concrete mix design for specific desired strength and properties.

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