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THE APPLICATION OF RESPONSE SURFACE METHODS (RSM) TO STUDY THE EFFECT OF PARTIAL PORTLAND CEMENT REPLACEMENT USING SILICA FUME ON THE PROPERTIES OF MORTAR

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ABSTRACT

The addition of pozzolan material, such as silica fume in order to improve mortar or concrete quality has been reported in many papers. However, the previous experimental design was only limited to factors that had a significant influence on the response. In addition, the results of the research analysis are only able to determine differences between the levels of factors and show the maximum or minimum response values, limited to the level of factors planned only. Response Surface Method used in the experiment of this study can analyze the problems of several independent variables that affect the response variable. The basic idea of this method is to use experimental design involving statistics to find the optimal value of the effect of adding silica fume as a partial substitute material for mortar to the compressive strength resulted. The design of the experimental proportion in this study was carried out by replacing 20% silica fume in cement as the middle boundary. Furthermore, the proportion of silica fume, cement and sand is reduced in number to the lower limit and added to the upper limit of the experimental design. Conclusions achieved; 1) Analysis using the Response Surface Method shows the optimal composition of mortar mixture obtained by adding 23.6% silica fume to cement, so that the optimal compressive strength test is at 55.8 MPa. 2) The optimal composition can also reduce the absorption of mortar to water, which only absorbs 5.34% water compared to mortar without silica fume which absorbs water up to 8.84%. 3) Addition of silica fume to mortar can increase 1.33% pH of mortar. The pH of the mortar with the addition of silica fume remained in alkaline conditions 9.75.

Key words: mortar, silica fume, response surface method, mortar characteristics.

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1. INTRODUCTION

Mortar is a mixture consisting of binder (cement), fine aggregate (sand), water, and other additives, which are used as constituent material in a construction that is both structural and non-structural. Mortar is a porous mixture that cannot be avoided from the entry of aggressive ions which can cause degradation. Mortar as the outermost layer of the wall that is degraded will become cracked and porous. Therefore, in an effort to prevent or reduce the occurrence of damage, what can be done is to make the concrete mixture denser (waterproof) so that it can withstand the effects of destructive acid [1].

Many studies have shown that an increase in compressive strength and reduced permeability in mortars and concrete with the addition of pozzolan material in form of silica fume. Silica fume contains high layers of SiO2 and is a very fine, round and very small diameter of material that is 1/100 times the diameter of cement. It can fill the cavity between particles in the mortar mixture, so that a more impermeable mortar is obtained [2]. Research presents an experimental study on self-compacting concrete (SCC) involving three types of mixtures, the first consisting of a different percentage of fly ash, the second using different percentages of silica fume and the third using a mixture of fly ash and silica fume. The results of this study is the mixtures of 15% silica fume as a substitute for cement resulting in a higher compressive strength compared to the mixture of 30% fly ash [3].

Silica fume also studied with variations of 0, 5, 10 and 20% in concrete mixtures. Testing of compressive strength on concrete specimens aged 7 and 28 days has increased, respectively 38.30 N / mm2, 41.29 N / mm2, 46.76 N / mm2, 47.3 N / mm2, and 44.27 N / mm2. The results of this study indicate that the use of silica fume can increase the strength of concrete. The optimum compressive strength and flexural strength are obtained in the range of 10-15% silica fume replacement [4]. Based on ref [5], study to determine the effect of silica fume on geopolymer concrete, using variations of silica fume as much as 5, 10, 15 and 20% as a partial substitute for cement. Tests were carried out on geopolymer concrete specimens aged 7 and 28 days. As much as 20% silica fume usage as a substitute for some cement, can increase the compressive strength by 9%, tensile strength up to 10% and flexural strength by up to 12%.

So far, the results of several studies on the addition of silica fume as a partial substitute for cement, only analyzed the effect of silica fume with simple statistical calculations. A study with an experimental design method is needed, which can take into account the influence of each constituent material (more than one factor) on the response of an experimental mortar mixture. One of the right methods used in experimental design is Response Surface Method. This method can contribute to the influence of two or more factors in an experiment [6]. The analysis using the surface response method resulted in the design of non-combustible bricks with a mixture of 21,034% cement, 28,9651% sand and 50% soil. With the proportion of the design of the constituent materials of the brick, optimal brick compressive strength was obtained at 50.22 kg/cm^2[7]. Experimental design modeling on mortar with the addition of silica fume as a partial substitute for cement has never been done before. In this research, an experimental design will be carried out with silica fume as a partial substitute for cement, which aims to obtain the optimum value and know its effect on the physical and mechanical properties of the mortar.

2. EKSPERIMENTAL PROGRAMS

2.1. Materials

The ingredients of the mortar in this study included PPC cement, sand, water and pozzolanic material, silica fume. Comparison of cement:sand in the mortar mixture used is 30:70 [8]. There are three independent variables namely the proportion of sand, the proportion of cement and the proportion of silica fume. The design of the initial mortar composition design will use 20% silica fume as a partial substitute for cement.

2.2. Mix Proportions

The research method used in this study is response surface method on Minitab program 17. Before being input into the Minitab, the design of the proportion of sand, the proportion of cement and the proportion of silica fume as much as 20% is determined as the middle level (code 0), then design proportions for the lower level (code -1) and the upper level (code 1) are obtained by reducing and adding the same number of proportions based on the composition at the middle level. The design can be seen in Table 1. The number of draft proportions in Table 1 is then input to the dialog box in the Minitab 17 program, by selecting Stat - DOE - Create response surface design. There are 20 types of sample designs, which are made with replication of 3 times. The experimental design can be seen in Table 2.

Table 1 Number of Mortar Mixed Material Design Proportions

Factor	-1 (gr)	0 (gr)	1 (gr)
Silica	90	120	150
Cement	300	480	660
Sand	1200	1400	1600

Table 2 Design of Response Surface CCD Experiments

No.	StdOrder	RunOrder	PtType	Blocks	Sand	Cement	Silica Fume
1	1	1	1	1	-1	-1	-1
2	2	2	1	1	1	-1	-1
3	3	3	1	1	-1	1	-1
4	4	4	1	1	1	1	-1
5	5	5	1	1	-1	-1	1
6	6	6	1	1	1	-1	1
7	7	7	1	1	-1	1	1
8	8	8	1	1	1	1	1
9	9	9	-1	1	-1.6817	0	0
10	10	10	-1	1	1.6817	0	0
11	11	11	-1	1	0	-1.6817	0
12	12	12	-1	1	0	1.6817	0
13	13	13	-1	1	0	0	-1.6817
14	14	14	-1	1	0	0	1.6817
15	15	15	0	1	0	0	0
16	16	16	0	1	0	0	0
17	17	17	0	1	0	0	0
18	18	18	0	1	0	0	0
19	19	19	0	1	0	0	0
20	20	20	0	1	0	0	0

3. RESULTS AND DISCUSSION

3.1. Compressive Strength

Testing the steps and spesification in making sample of mortar that is implemented in this research as directed by reference [9] using a Compressive Testing Machine (CTM) [10]. The results can be seen in Table 3.

Table 3. Compressive Strength Test Results

No	Design of Experiment (gr)			Compressive Strength (MPa)		
	Silica Fume	Cement	Sand	1	2	3
1	90	300	1200	30.800	30.500	31.200
2	150	300	1200	42.000	43.500	44.400
3	90	660	1200	40.392	39.216	39.500
4	150	660	1200	40.800	41.200	39.500
5	90	300	1600	32.500	33.200	32.800
6	150	300	1600	40.500	41.212	41.500
7	90	660	1600	42.500	44.400	43.500
8	150	660	1600	38.000	38.400	39.500
9	69.57	480	1400	18.500	18.846	18.077
10	170.43	480	1400	26.500	27.200	27.600
11	120	177.42	1400	45.500	46.000	44.800
12	120	782.58	1400	52.400	51.500	51.200
13	120	480	1063.8	46.500	47.755	47.500
14	120	480	1736.2	47.500	49.200	48.500
15	120	480	1400	56.500	56.800	56.500
16	120	480	1400	56.500	56.500	56.078
17	120	480	1400	56.500	56.500	56.500
18	120	480	1400	56.500	56.000	56.500
19	120	480	1400	57.959	57.143	56.500
20	120	480	1400	56.500	56.800	56.500

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	7029.65	781.07	1914.46	0.000
Linear	3	351.49	117.16	287.17	0.000
Silica Fume	1	213.49	213.49	523.27	0.000
Cement	1	135.15	135.15	331.27	0.000
Sand	1	2.85	2.85	6.98	0.011
Square	3	6410.48	2136.83	5237.51	0.000
Silica Fume*Silica Fume	1	6158.81	6158.81	15095.69	0.000
Cement*Cement	1	344.05	344.05	843.28	0.000
Sand*Sand	1	410.90	410.90	1007.15	0.000
2-Way Interaction	3	267.68	89.23	218.70	0.000
Silica Fume*Cement	1	229.53	229.53	562.58	0.000
Silica Fume*Sand	1	36.46	36.46	89.36	0.000
Cement*Sand	1	1.70	1.70	4.16	0.047
Error	50	20.40	0.41		
Lack-of-Fit	5	3.35	0.67	1.77	0.139
Pure Error	45	17.05	0.38		
Total	59	7050.05			

Table 4. Analysis of the Order Response Surface Regression Model

3.2. The Second-Order Model Analysis of Variance

Test results of compressive strength in table 3 then analyzed using Response Surface Design in the Minitab 17 program, by selecting Stat - DOE - Response Surface - Analyze Response Surface Design, click Term and select the quadratic model. Quadratic experimental design is used to determine whether the input variable in the compressive strength data has a significant effect or not. Data processing in experiment stage II obtained results as shown in Table 4.

As it can be seen in table 4, it is known that the P value obtained is smaller than the value of α (pvalue <α) = 0.05. This indicates that the independent variable contributes significantly to the model formed. The Lack of Fit test results are significant, which is indicated by (pvalue> α) = 0.139 so that the hypothesis H_0 is accepted, meaning that there is a suitability of the model or there is no incompatibility of the analysis model.

3.3. Testing the Experimental Model

3.3.1. Identical Test

Testing of identical assumptions aims to examine whether the residual variance of the model obtained is the same as the spread. In Figure 1 below, residuals are scattered randomly and do not form a certain pattern. This shows that identical residual assumptions are fulfilled.

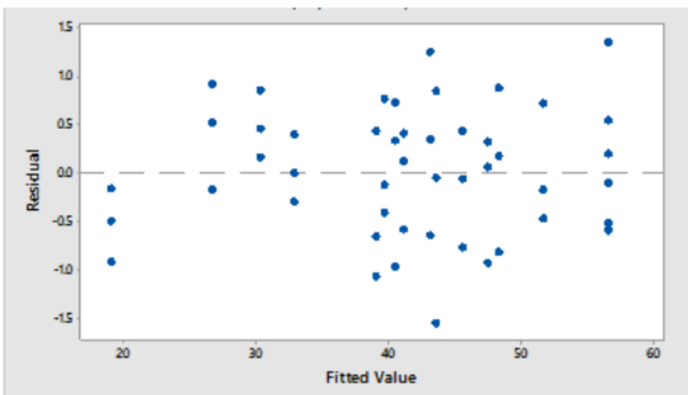


Figure 1. Identical Residual Vs Fits Test

3.3.2. Normal Distribution Test

Figure 2 shows the results of the Kolmogorov-Smirnov (KS) statistic for the normal distribution test. The Kolmogorov-Smirnov statistical value is 0.136 less than the Kolmogorov statistical value of 0.210 means that the residual normality test has followed the normal distribution. The residual plot of response approaches a straight line, so it can be said that the error does not deviate from the normal distribution substance. If the response is not normally distributed, it can be due to the form of the regression function which is incorrect or inappropriate. With the three residual analyzes above, it can be concluded that the residual test is identical, independent and normally distributed.

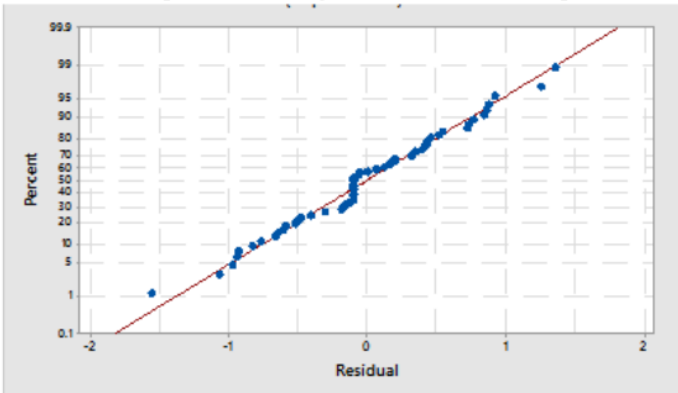
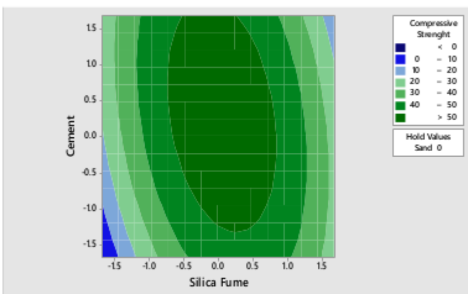


Figure 2. Normal Distribution Test

3.4. Analysis of Response Surface Characteristics

The running result of the response surface program produces two images in the form of a contour graph and graph surface as shown in Figure 3 and Figure 4 below:



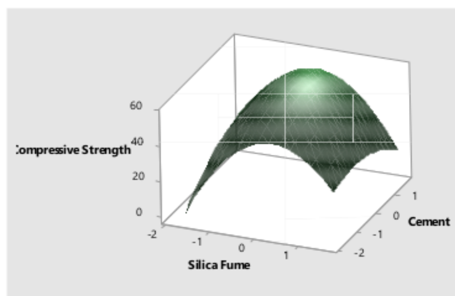


Figure 3. Plot Contour

Figure 4. Plot Surface

In Figure 3 each variation shows the range of the magnitude of the response produced. The maximum conditions for the plot above are in dark green with a compressive strength above 50 kg / cm2. This color range will outline the direction of the optimum variable point. Determination of the optimum conditions of the above factors is proofed by the form of a three-dimensional curve that procedures the optimum peak as shown in Figure 8. The plot surface image in Figure 8 displays the contour plot in three dimensions. In the picture above, optimum compressive strength is between level 0 and 1 addition of silica fume and cement.

3.5. Optimization

The optimization results in Minitab 17 by using response surface method are shown in Figure 5. The graph results show the proportions for each independent variable which produces the most optimum response variable. The variable Silica Fume is at the level of 0.0510, which is as much as 121.53 gr. The cement variable is at the level of 0.2888, which is 514.65 gr, and the sand variable is at the level of 0.0493, which is 1409.86gr. The results of this optimization show the optimum composition that can be obtained by mortar, with the addition of silica fume as much as 23.6%.

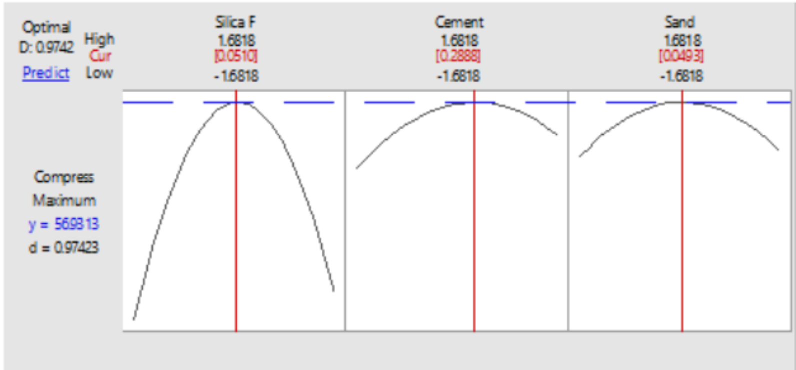


Figure 5. Optimum Plot

The result of this response surface optimization method is then re-tested to find out the quality confirmation design produced. This confirmation design was made with three samples with material composition based on the optimization results. This confirmation design was also carried out on testing the absorption and pH, which was in the form of analyzing the physical and mechanical properties of the mortar.

3.6. Compressive Test Confirmation Results

The results of testing the mortar mixture with 23.6% silica fume obtained from the optimum plot were then compared with mortar without silica fume content. Mortar without added silica fume ingredients has a compressive strength of 25.6 MPa. The value of compressive strength on the confirmation mortar optimization results increased to reach 55.8 MPa. The value is shown in Figure 6.

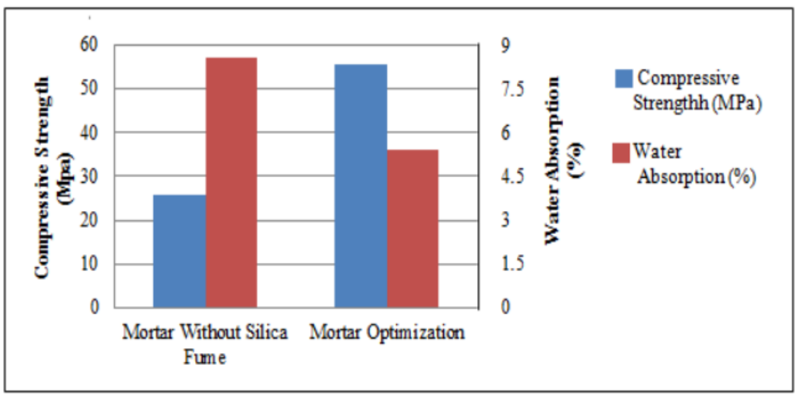


Figure 6. Comparison of Mortar testing result

3.7. Water Absorption Test Results

Water absorption test of mortar is done by soaking the 56 days old specimen in water for 24 hours then the surface is dried awaiting no more water drips and then weighs the weight. Then the tested object is put into an oven with a temperature of 1100 for 24 hours then weighed again. Figure 6 shows a comparison of the mortar without silica fume with an optimized mortar by adding 23.6% silica fume. Mortar resulted from response surface methods optimization, can reduce water absorption by up to 5.43% compared to 8.84% absorptive silica mixtures. The results of 56 day mortar optimization can be seen in Table 6.

Table 5. Results of Absorption Test on Mortar

No	Silica Fume (gr)	Cement (gr)	Sand (gr)	SSD (gr)	SD (gr)	WA (%)	Average WA (%)
1	0	600	1400	306.53	279.34	8.87	
2	0	600	1400	311.75	283.99	8.905	8.848
3	0	600	1400	294.24	268.44	8.768	
4	121.53	514.66	1409.86	299.7	285.89	4.608	
5	121.53	514.66	1409.86	297.56	281.23	5.488	5.438
6	121.53	514.66	1409.86	293.75	275.48	6.22	

SSD : Saturated Surface Dry SD : Surface Dry WA : Water Absorption

3.8. Mortar pH Test Results

The pH test on mortar without silica fume additives compared with mortar with the addition of the optimized silica fume can be seen in Figure 7. The pH test results showed that the mortar without silica fume had a pH of 9.63, whereas with the addition of silica fume, the optimization results in pH 9.75. Addition of silica fume as a substitute material for cement in mortar can maintain pH. The mortar remains alkaline according to the provisions of the pH of the mortar, which is> 9, so the function of the mortar to protect the reinforcement inside it from destructive acid is remain intact.

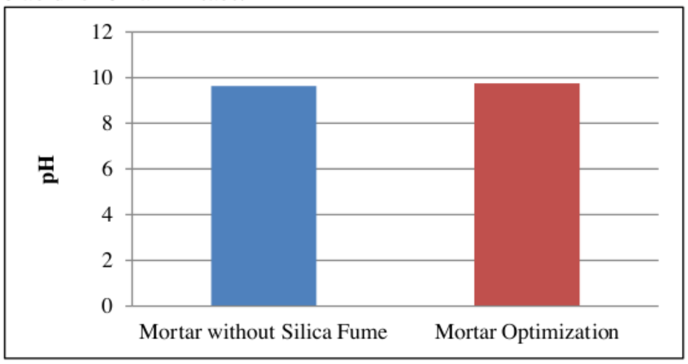


Figure 7. pH Comparison of Mortar

4. CONCLUSION

The primary conclusion drawn was that the method used in this study has demonstrated the inferential results of an experimental work in civil engineering field. More specific outcomes are outlined as follows:

1) The results of analysis with Response surface method produce, the optimum proportion of mortar is obtained by the composition of silica fume : cement : sand, which is 121.53 gr : 514.65 gr : 1409.8 gr. The results of testing the optimal confirmation test obtained compressive strength of 55.8 MPa, higher than the mortar compressive strength without silica which is 25.6 MPa.
2) Adding 23.6% of the silica-fume material from the optimum composition, is able to optimize the mortar mixture to be more waterproof. This is known from the decrease in water absorption on mortar up to 5.43% compared to mortar without silica which absorbs up to 8.48% water

3) The results of pH testing to the mortar with additional silica fume material showed that the mortar remained in an alkaline state (> 9).

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