The Design Experiment

by Civil Engineering Department Mataram University

The Design of Experiment : An Optimization of Mortar Mixture Composition with Silica Fume As Partial Replacement For Cement

Gagassage Nanaluih De Side[1], Ni Nyoman Kencanawati[2], Hariyadi[3]

[1,2,3] *Master of Civil Engineering Program, Department of Civil Engineering University of Mataram, West Nusa Tenggara, Indonesia*

Abstract: In an effort to produce better mortar quality, a quality control method is required. The purpose of this research was to determine the proportion of the material with the optimum partial replacement of cement by silica fume to the compressive strength of the 56-days mortar, where the focus of quality control shifted to the earlier stage of product design stage. The further research is needed to determine the actual optimum proportion. This research uses 3 factors, which are the proportion of silica fume, the proportion of sand, and the proportion of cement, for each factor consists of 3 levels, with the content of silica fume is ±20% from weight of cement. Mortar is based on 9 combinations of materials on the orthogonal matrix $L_9(3^4)$ then created with dimensions 50 mm^3 cube. The results show that the optimum proportion is 150 gr of silica fume, 660 gr of cement and 1400 gr of sand which is equivalent to replacing 22,7% cement with silica fume, which gain 54,00 MPa compressive strength.

Keywords: compressive strength, mixture composition, mortar, optimization, silica fume

I. INTRODUCTION

In order to increase the mortar quality dan decrease the used of cement, the addition of additive substance (extra materials) are needed. The commonly used materials are silica fume, fly ash, rice husk ash, and other additive substances. Based on the research that has been conducted by ref [1], concrete with the mixture of 15% of silica fume as the substitute of cement gives the higher compressive strength compared to 30% of fly ash. Silica fume is a very effective pozzolan dan has high ratio of water-cement. Silica fume 0% for 10% as the substitusion, 0,5 kg silica fume can replace 1,5 to 2 kg cement in concrete without changing the compressive strength [2].

A quality control method is required to produce better mortar quality. The used of a set of orthogonal array (OA) will be included in the design experiment in order to give maximum result in accordance with the condition of affecting factors and effective parameter, thus the researcher can achieve the expected result [3].

Reference [4] shows that the effect of the addition of silica fume to mortar physical and mechanical properties, where the result shows that the addition of pozolan silica fume as a whole significantly affecting the more waterproof mortar which is marked by the decreasing of water absorption, producing the mortar in basa condition which is relatively safe for reinforced concrete column in it, and increasing the compressive strength of mortar. Based on the three tested parameter; water absorpsion, pH, dan compressive strength, it is shows that the proportion of silica fume mixture can be increased to discover the optimum proportion. Thus, this research is conducted to achieve an alternative in concrete tchnology, by replacing half of cement with silica fume to produce a better mortar quality.

The aim of this research is to determine the proportion of the materials with optimal substitusion of cement by silica fume toward the compressive strength with time span 56 days . The making of sampel and the mortar compressive strength test according to reference [5] [6]. This research used 3 factors, those are proportion of silica fume, proportion of sand, and proportion of cement, each factor consist of 3 levels, with silica fume replace from weight of cement. Mortar is based on 9 combinations of materials on the orthogonal matrix $L_9(3^4)$ by mixing the silica fume, sand, cement, and water, then created with dimensions 50 mm^3 cube.

II. METHODS

The result of preliminary experiment is the basic in deciding the 3 *level* references that will be used in Design of Experiment (DOE). The combination of that reference is used as the value on *medium level* (*level* 2), where on *level* 2 the material combination are 120 gr of silica fume : 480 gr of cement : 1400 gr of sand or equal with the substitusion of 20% cement with silica fume and the comparison of cement:sand is 30:70 [7].

For the value on *high level* (*level* 3), the higher value than level 2 is used, meanwhile on *low level* (*level* 1), the lower value than *level 2* is used. The result of the value in *level* factor is shown in Table 1.

Table 1. The Total Amount of Level and Factor Level Value

Factor	Level 1(gram)	Level 2 (gram)	Level 3 (gram)
Silica fume (A)	90	120	150
Cement (B)	300	480	660
Sand (C)	1200	1400	1600

The value of factor *level* in Table 1 will be combined based on the combination of ortogonal matrix $L_9(3^4)$ as in Table 2.

Table 2. The Combination of Factor Level on Ortogonal Matrix L9(3^4)

Exp.	Ortogonal Matrix $L_9(3^4)$ Factor			The Mixture of Materials Based on Ortogonal Matrix $L_9(3^4)$ (in gram)			(in percentage)		
	A	B	C	A	B	C	A	B	C
1	1	1	1	90	300	1200	5,66	18,87	75,47
2	1	2	2	90	480	1400	4,57	24,37	71,07
3	1	3	3	90	660	1600	3,83	28,09	68,09
4	2	1	2	120	300	1400	6,59	16,48	76,92
5	2	2	3	120	480	1600	5,45	21,82	72,73
6	2	3	1	120	660	1200	6,06	33,33	60,61
7	3	1	3	150	300	1600	7,32	14,63	78,05
8	3	2	1	150	480	1200	8,20	26,23	65,57
9	3	3	2	150	660	1400	6,79	29,86	63,35

Description:
A = silica fume, B = cement, C = sand

III. RESULT AND DISCUSSION

3.1. The Analysis of the Affecting Factor Toward the Mean of Mortar Compressive Strength

After the value of mortar compressive strength is obtained, the next step is calculating the mean of mortar compresive strength for each experiment. The result of mean of mortar compressive strength for each experiment and the mean of mortar compressive strength as a whole is shown in Table 3. From the calculation of mean in Table 3, then the mean of mortar compresssive strength for every factor level is calculated. The result of calculation for all of the factor levels is shown below.

Table 3. The Result of Calculation Of Mean Of Mortar Compressive Strength

Experiment	Ortogonal Matrix L9(3^4) Factor A	B	C	Compressive Strength (MPa) A	B	C	Total	Mean
1	1	1	1	44,80	49,39	37,60	131,79	43,93
2	1	2	2	48,00	54,69	52,00	154,69	51,56
3	1	3	3	54,29	52,80	40,80	147,89	49,30
4	2	1	2	41,20	42,75	42,40	126,35	42,12
5	2	2	3	38,00	44,80	58,43	141,23	47,08
6	2	3	1	53,20	44,80	53,06	151,06	50,35
7	3	1	3	47,60	40,00	41,20	128,80	42,93
8	3	2	1	48,40	52,80	56,00	157,20	52,40

9	3	3	2	55,59	52,90	54,00	162,49	54,16
				Total				433,83
				Mean				48,20

Description:
A = silica fume, B = cement, C = sand

Based on the mean of mortar for every factor level, then the main effect plot is made for mean of mortar compressive strength. Main effect plot is needed to facilitate the analysis of optimum level for mean of mortar compressive strength.

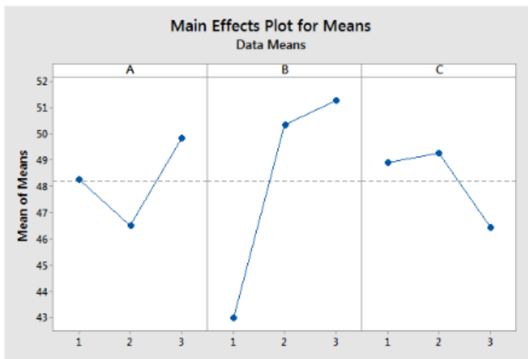

Fig. 1. Main Effect Plot Mean of Mortar Compressive Strength

The value of data means is drawn graphically on main effect plot graph in Fig. 1 is using Minitab 17 program. According to characteristics quality the larger the better, thus the decision of maximum factor level is the one who has the largest mean of mortar compressive strength among the three levels in each factor. From the main effect plot on Fig. 1, thus the optimum levels chosen for optimizing mortar compressive strength is level 3 for factor A, level 3 for factor B, and level 2 for factor C.

3.2. The Analysis of Affecting Factors toward Signal Value to Noise Ration (SNR)

Factors that may have contribution on decreasing the variation and increasing the mean can be identified by analyzing the effect of factor toward SNR as well as analyzing the effect of factor toward mean or mortar compressive strength. Signal to Noise Ratio (SNR) changes the mortar compressive strength into a number until the biggest factor level can be chosen to optimize the value of mortar compressive strength. The basic principle is the setting of factor level reach the optimum condition if the value of SNR can be maximized. The result of calculation for SNR for each experiment is shown in Table 4.

Table 4. The Result of Calculation for the Value of SNR for Each Experiment

Orthogonal Matrix L9(3^4)				Compressive Strength (MPa)			SN
Experimen	Factor						
	A	B	C	A	B	C	
1	1	1	1	44,80	49,39	37,60	32,69
2	1	2	2	48,00	54,69	52,00	34,21
3	1	3	3	54,29	52,80	40,80	33,64
4	2	1	2	41,20	42,75	42,40	32,49
5	2	2	3	38,00	44,80	58,43	33,06
6	2	3	1	53,20	44,80	53,06	33,96
7	3	1	3	47,60	40,00	41,20	32,58
8	3	2	1	48,40	52,80	56,00	34,34

9	3	3	2	55,59	52,90	54,00	34,67
			Total				301,62
			Mean				33,51

Description:
A = silica fume, B = cement, C = sand

Based on value of SNR from the calculation, then the value response of SNR from affecting factors is calculated. The value response of SNR is calculated for each level on that factor as in the calculation of value response on mean of mortar compressive strength, the result of the calculation for all of factor level is shown in main effect plot in Fig.2. It can be seen that cement is the most affecting factor toward the variation of mortar compressive strength value since it is on the first place, followed by silica fume and sand. The value is drawn graphically in Fig. 2.

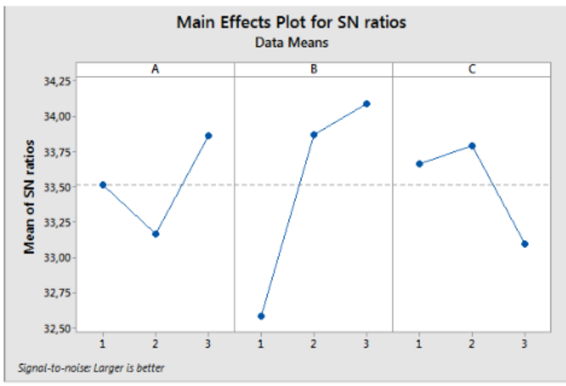

Fig. 2. The Value of Signal Main Effect Plot to Noise Ratio (SNR) of Mortar Compressive Strength

3.3. Determining the Setting Level Optimum

In order to find out which factor that has most significant contribution, F-ratio on the result of ANOVA has to be considered. By considering F-ratio, a factor can be classified as significantly affecting the mean of mortar compressive strength if F-ratio is bigger than F-table [8], where F-table for $\alpha = 5\%$ with factor degree of freedom is (V1) = 2 and error freedom degree (V2) = 2, thus the F-table is (F0,05; 2; 2) = 19,00.

The result of Minitab 17 that by comparing F-ratio, factor A has F-ratio 48,98 > F-table 19,00 (significant), factor B has F-ratio 366,06 > F-table 19,00 (significant), factor C has F-ratio 42,38 > F-table 19,00 (significant).

Setting level optimum is chosen by considering the factors that might be combines to decrease the variation and optimize the mortar compressive strength. The result of setting level optimum for all of the factors on mortar experiment is shown in Table 5.

Table 5. Setting Level Optimum for Each Factors

Factor	Level	Setting
A (silica fume)	3	150 gram
B (cement)	3	660 gram
C (sand)	2	1400 gram

3.4. The Result of Design of Experiment and The Comparison with Mortar without Silica Fume

The optimum mortar conditions have been compared with confirmation experiments, where the optimum condition confidence interval is in the confirmation condition interval. Then this condition is compared with the condition of the mortar without silica fume, shown in Fig. 3. Thus, the condition of optimum factor level can be accepted and it can be concluded that the setting of factor level combination is on optimum condition that has been gained is valid.

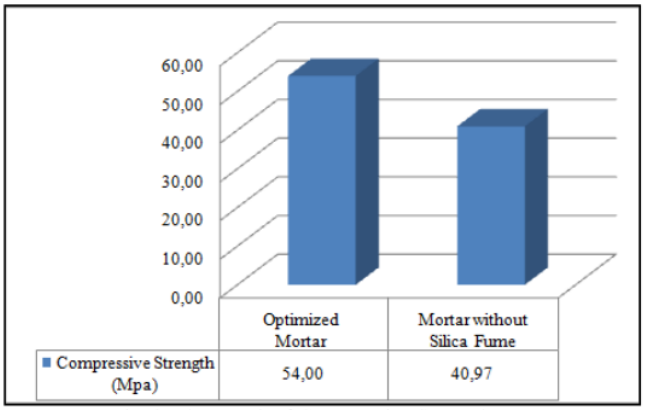

Fig. 3. The Result of Compressive Strength Test

IV. CONCLUSIONS

All of three factors that significantly affecting the mean and variation of mortar compressive strength are 10,466% of silica fume, 79,634% of cement, and 9,027% of sand. Factor contribution toward variation or SNR are 12,815% of silica fume, 71,101% of cement, and 14,528% of sand.

Mortar optimum composition are 150 gr of silica fume : 660 gr of cement:1400 gr of sand or equal as 22,7% silica fume replacement for cement that produce mortar compressive strength until 54,00 MPa. The compressive strength for mortar was 24,13% higher than the mortar without silica fume as much as 40,97 MPa.

REFERENCES

[1] Mohamed, H. A, *Effect of fly ash and silica fume on compressive strength of self-compacting concrete under different curing conditions*, Ain Shams Engineering Journal, 2(2), 79-86, 2011.

[2] Malhotra, V. M., and Carette, G. G, *Silica fume,* Concrete Construction, 27(5), 443-446, 1982.

[3] Krishnaiah, K. and Shahabudeen, P, *Applied design of experiments and Taguchi methods*, PHI learning Pvt. Ltd, 2012.

[4] Fajrin, J., Pathurahman, and Pratama L.G, *Aplikasi Metode Analysis Of Variance (Anova) untuk Mengkaji Pengaruh Penambahan Silica Fume Terhadap Sifat Fisik dan Mekanik Mortar,* Jurnal Rekayasa Sipil (JRS-Unand),. 12(1): p. 11-23, 2016.

[5] SNI, S, SNI 03-6825-2002 *Metode Pengujian Kekuatan Tekan Mortar Semen Portland untuk Pekerjaan Sipil*, 2002.

[6] Umum, D. P, *Tata Cara Pembuatan dan Perawatan Benda Uji Beton di Laboratorium SNI 2493-2011,* Badan Standarisasi Nasional, Bandung, 2011.

[7] Umum, D. P., *Spesifikasi Mortar Untuk Pekerjaan Pasangan*. SNI 03-6882-2002, Badan Standarisasi Nasional, Bandung, 2002.

[8] Soejanto, I., *Desain Eksperimen dengan Metode Taguchi*. Graha Ilmu, Yogyakarta, 2009.

The Design Experiment

ORIGINALITY REPORT

8%	5%	4%	5%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Federal University of Technology Student Paper	5%
2	eprints.unram.ac.id Internet Source	2%
3	www.iaeme.com Internet Source	1%
4	article.sapub.org Internet Source	1%

Exclude quotes	On	Exclude matches	< 1%
Exclude bibliography	On		

The Design Experiment

GRADEMARK REPORT

FINAL GRADE

/0

GENERAL COMMENTS

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5