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Optimization of cellular lightweight concrete using silica sand of sandblasting waste based on factorial experimental design

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Abstract. Sandblasting is a surface treatment that serves to clean the surface, improves adhesion strength and bonding performance, which in the process produces silica sand waste. Silica sand of sandblasting waste can be used as a lightweight concrete type of Cellular Lightweight Concrete (CLC). The experimental design was used factorial to find out factors influencing the compressive strength of lightweight concrete and to find the optimum composition of lightweight concrete with maximum compressive strength. The results showed that Portland cement composition and the ratio of foam significantly influenced the compressive strength of lightweight concrete with silica sand waste of sandblasting as aggregate. The optimum compressive strength of 86.13 kg/cm^2 was found in the composition of Portland cement by 40%, silica sand 40% and volume ratio foam to mortar 0.6.
Keywords: silica sand, cellular lightweight concrete, factorial

1. Introduction

Sandblasting is a mechanical process by high-speed shooting sand particles that are produced by compressed air [1]. Surface treatment serves to clean the surface, increase strength adhesion and bonding performance through surface roughness modification [2]. Sandblasting activities will leave the remaining form of waste of silica sand that is not utilized [3]. Taiwan produces 2186 tons of sandblasting waste every year [4].

Silica sand of sandblasting waste includes Hazardous and Toxic Substances waste because it contains heavy metals which have a negative impact on health [5]. Silicosis is a disease that can be caused by the entry of silica particles into the breathing [1]. Silica sand waste has been used in several products, such as coagulants [5], paving blocks [6], concrete [7] and asphaltic concrete [8]. Silica sand is pozzolan material which can hydrated if mixed with Portland cement and water to produce substances that have binding abilities [9]. One of the potential applications is using silica sand as aggregates in lightweight concrete.

Lightweight concrete is a mixture of cement with aggregates which produces a density between 300 and 2000 kg/m^3 [10]. Lightweight concrete has several advantages such as high compressive strength [11], good fatigue performance [12], high thermal insulation [13] and low density [14]. Lightweight concrete has been produced with various materials such as manufactured plastic [15], polyethylene beads [10], polyvinyl alcohol [12], fly ash [16], bauxite residue [17], and phosphogypsum [18].

Cellular lightweight concrete is a type of lightweight concrete made from cement paste or mortar which contains air bubbles produced by foam agent [19]. Cellular lightweight concrete has good performance, such as low density, acoustic insulation and thermal insulation [20]. Foam is produced with foam agent which can be made from natural protein or synthetic material [21]. Foam mixed with mortar will increase the volume of mortar due to trapped air so that the density will decrease.

The full factorial design is employed to optimize the compressive strength of lightweight concrete, by optimizing the composition of lightweight concrete with high compressive strength. The full factorial experiment provides more practical and reliable results compared to fractional factorial design [22]. The study investigated the effect of composition and interaction of Portland cement, silica sand, and foam on compressive strength of cellular lightweight concrete.

2. Experimental Procedure

2.1. Materials and Methods

Lightweight cellular concrete is synthesized from Semen Gresik Portland cement, sand, silica sand waste of sandblasting process, foam agent and water. Portland cement, sand and silica sand mixed until homogenous with a mixer for 1 minute. Water is added with stirring for 1 minute, then added foam that has been made with a foam generator. The paste is put into the mould and opened after 24 hours. Density and compressive strength tests were carried out on concrete that had been curing for 28 days.

2.2. Design Experiment

The Factorial experimental design is using to optimize the compressive strength of the concrete. Controlled factors in this research are Portland cement, silica sand, and the volume ratio of paste: foam. Table 1 presents levels of the three factors coded by A, B, and C.

Table 1. Controlled Factor.

Factor	Level		
	-1	0	+1
A – Portland cement (%)	20	30	40
B – Silica sand (%)	20	40	60
C – Paste:foam (v/v)	0.4	0.5	0.6

3. Results and Discussion

27 runs of experiment with different factors and levels were conducted, each run was carried out with 3 replications. Table 2 shows the results of a compressive strength test of lightweight concrete. The result of the normality test of compressive strength shown in Fig. 1. It can be seen that the p-value is 0.082 which is greater than α (0.05) and the distribution of residuals are almost on the diagonal line, so it can be concluded that compressive strength test data is normally distributed. Table 3 shows the quadratic model of the result of ANOVA, the p-value is used to determine whether or not the factor has a significant effect on compressive strength lightweight concrete. Factors have a significant effect on the compressive strength of lightweight concrete if the p-value less than α (0.05).

Analysis of variance result indicated that the Portland cement has a p-value of 0.019 smaller than the α (0.05) so it can be concluded that Portland cement has a significant effect on compressive strength of cellular lightweight concrete. Fig. 2 showed that the addition of the composition of Portland cement would improve the compressive strength of cellular lightweight concrete, an increase in the composition of Portland cement would increase the availability of cement paste to bind aggregate particles [23]. In addition, an increase in the amount of Portland cement provides an opportunity for water to improve compacting factor [24], so that the compressive strength increases.

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Table 2. Results of experiments.

Run	Controlled Factor	Uncontrolled Factor	Compressive Strength (Kg/cm^2)					
	Portland cement (%)	Silica sand (%)	Paste: foam (v/v)	Sand (%)	Rep. 1	Rep. 2	Rep. 3	Average
1	30	20	0.5	50	12.00	11.20	10.80	11.33
2	40	40	0.4	20	10.00	5.60	6.00	7.20
3	20	40	0.5	40	2.40	4.00	4.00	3.47
4	40	40	0.6	20	86.00	87.60	84.80	86.13
5	30	20	0.4	50	4.00	6.00	6.00	5.33
6	20	40	0.6	40	8.80	6.80	8.00	7.87
7	30	60	0.4	10	4.80	2.80	8.00	5.20
8	40	20	0.6	40	10.00	8.00	8.40	8.80
9	30	60	0.6	10	42.00	35.60	23.60	33.73
10	40	60	0.6	0	16.80	20.80	16.00	17.87
11	30	40	0.4	30	6.00	8.40	5.20	6.53
12	40	60	0.5	0	56.16	50.64	53.64	53.48
13	40	20	0.4	40	22.00	28.40	30.00	26.80
14	40	20	0.5	40	18.00	24.40	38.00	26.80
15	20	60	0.4	20	4.80	2.80	8.00	5.20
16	20	20	0.6	60	12.00	12.00	9.60	11.20
17	40	60	0.6	0	8.00	18.00	18.40	14.80
18	40	40	0.5	20	12.00	12.00	9.60	11.20
19	30	20	0.6	50	16.00	18.00	16.40	16.80
20	20	60	0.5	20	4.00	2.80	3.60	3.47
21	30	40	0.5	30	12.80	36.40	14.40	21.20
22	30	40	0.4	30	8.08	10.00	11.20	9.76
23	20	20	0.5	60	10.40	12.00	10.40	10.93
24	20	60	0.6	20	14.00	38.00	46.40	32.80
25	30	60	0.5	10	10.00	12.00	10.80	10.93
26	20	20	0.4	60	3.60	4.80	2.80	3.73
27	20	40	0.4	40	29.20	30.00	32.40	30.53

Silica sand has no significant effect on compressive strength of lightweight concrete, this is indicated by the p-value of 0.304 which is greater than the alpha value (0.05). Mazloom *et al.* [25] said that the compressive strength of concrete mixtures containing silica fume did not increase after the age of 90 days. Fig. 2 shows that compressive strength of lightweight concrete increased with the use of silica sand up to 40% and then decreased with 60% usage. Kerai Jignesh *et al.* [26] in their study revealed that the use of 50% silica sand can increase the compressive strength of concrete.

Table 3. Analysis of Variance.

Source	DF	Adj SS	Adj MS	F-value	P-value	
Portland Cement	2	2270.9	1135.43	4.25	0.019	Significant
Silica Sand	2	649.3	324.63	1.21	0.304	Not-significant
Paste: Foam	2	2169.0	1084.5	4.06	0.022	Significant
Portland Cement*Silica Sand	4	889.8	222.44	0.83	0.510	Not-significant
Portland Cement* Paste: Foam	4	1395.4	348.85	1.31	0.278	Not-significant
Silica Sand* Paste: Foam	4	2530.4	632.60	2.37	0.062	Not-significant
Lack of fit	7	15037.7	2148.24	77.25	0.000	Significant
Pure error	55	1529.5	27.81			
Total	80	27181.6				

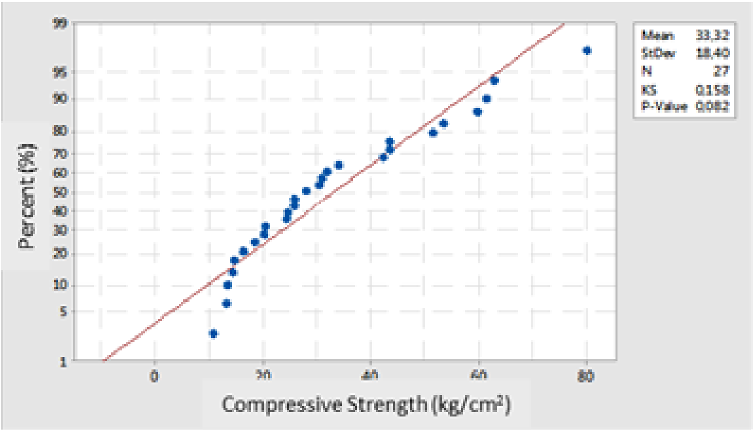

Figure 1. The result of normality test.

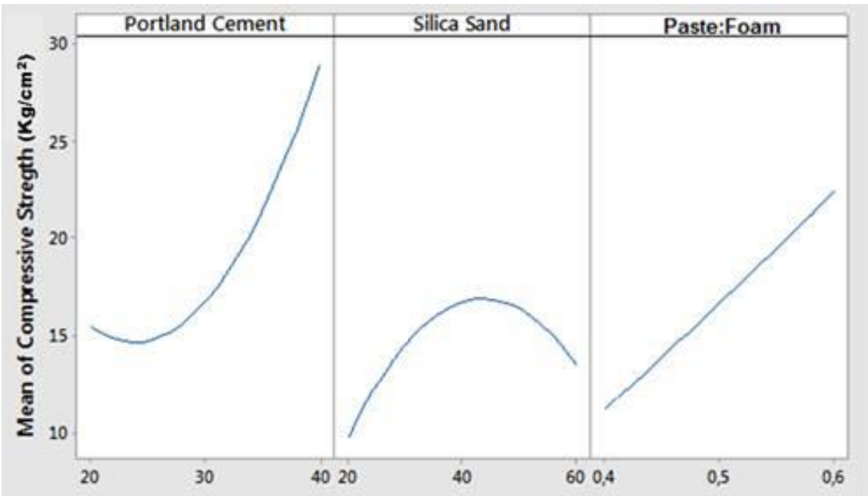

Figure 2. Main effects plot for compressive strength.

The ratio of Paste: Foam has a significant effect on the compressive strength of lightweight concrete because it has a p-value of 0.022 which is smaller than the α (0.05). The function of foam in cellular lightweight concrete is forming an air cavity in the concrete, resulting in low-density concrete. Fig. 2.

indicates that more amount of paste than foam produces greater compressive strength. Increasing the amount of foam will produce a greater volume of concrete because the air cavity is formed more. Increased concrete volume causes the density of the concrete to decrease so that the compressive strength decreases as well.

Analysis of variance showed that all of the interaction has a p-value higher than 0.05, so it can be concluded that there is no interaction between factors that occur in the synthesis of lightweight concrete using silica sand of sandblasting waste. This is also seen in Fig. 3 that there are no intersecting lines indicating no interaction between controlled factors.

Based on the experiment, optimum composition of lightweight concrete using silica sand of sandblasting waste are Portland cement by 40%, silica sand by 40%, the ratio of paste: foam by 0.6. The composition produces lightweight concrete with a density of 1706.67 kg/m^3 and compressive strength of 86.13 kg/cm^2, this lightweight concrete can be used as lightweight insulation concrete.

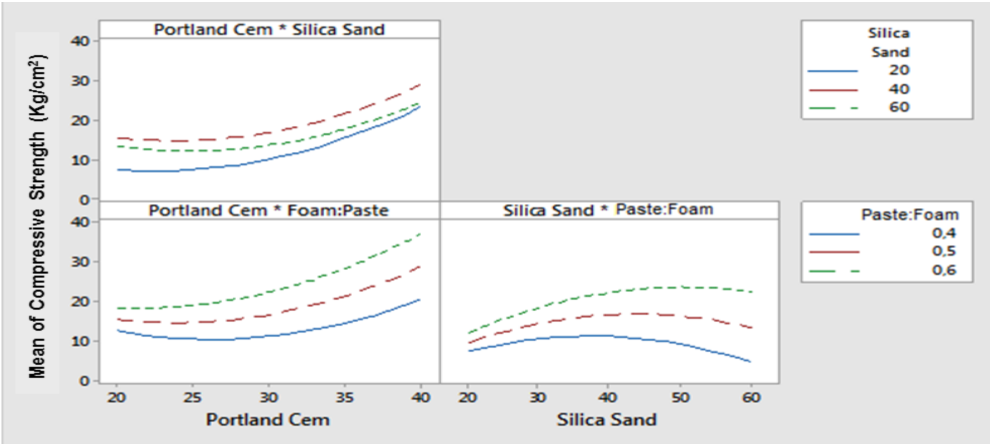

Figure 3. Interaction plot for compressive strength.

4. Conclusion

Based on the result of the research, the conclusion is as follows: (i) Portland cement and ratio of paste: foam have a significant effect on the compressive strength of cellular lightweight concrete using silica sand of sandblasting waste. (ii) The optimum composition of cellular lightweight concrete in this study was Portland cement by 40%, silica sand by 40%, the ratio of paste: foam by 0.6. (iii) The compressive strength of the optimum composition cellular lightweight concrete was 86.13 kg/cm^2 and density of 1706.67 kg/m^3.

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