The Effect of Silica Fume Admixture on the Compressive Strength of the Cellular Lightweight Concrete

by Reni Suryanita

Submission date: 12-May-2022 10:22PM (UTC+0700)
Submission ID: 1834693221
File name: Article_Reni_Suryanita_turnitin.pdf (918.19K)
Word count: 5367
Character count: 25891

The Effect of Silica Fume Admixture on the Compressive Strength of the Cellular Lightweight Concrete

Reni Suryanita*[1], Harnedi Maizir[2], Rizki Zulapriansyah[1], Yon Subagiono[1], Mohd Arshad Mohd Fadzil[3]

[1] Civil Engineering Department, Universitas Riau, Pekanbaru, Riau, Indonesia
[2] Civil Engineering Department, Sekolah Tinggi Teknologi Pekanbaru, Pekanbaru, Indonesia
[3] Faculty of Civil Engineering ,Universiti Teknologi MARA, Shah Alam Selangor, Malaysia

Corresponding author: * reni.suryanita@eng.unri.ac.id

HIGHLIGHTS

- The use of foam concrete in construction materials can reduce the load on the building foundation.
- The effect of silica fume admixture on the compressive strength of foam concrete is investigated.
- The addition of silica fume to the foam mortar mixture has increased the strength of foam concrete.

ABSTRACT

Foam concrete has practical and economic advantages in construction, including reducing the structure's weight by building foundations. The market demand for foam concrete such as Cellular Lightweight Concrete (CLC) block has increased recently. One way to reduce the density of CLC is to add air pores to the cement paste or mortar mixture. However, the addition of pores can reduce the strength of lightweight bricks. Therefore, there is a need for innovation to improve the quality of CLC block by replacing some of the cement with other added materials. This study aims to obtain a good quality CLC block using silica fume to replace partial cement in a mortar mixture. The specimens are a CLC block measuring 10 cm wide, 20 cm high and 60 cm long. Variation of mortar mixture using silica fume percentage of 0%, 5%, 10%, 15% and 20% of cement weight. The output data generated from this sample are compressive strength, displacement, stress, strain and the modulus of elasticity. The test results obtained the optimum CLC compressive strength of 1.03 MPa at 10% silica fume composition. This optimum compressive strength of CLC was simulated using the LUSAS finite element analysis to obtain the displacement and stress-strain patterns. Based on the LUSAS numerical analysis, the optimum compressive strength of the CLC block was 1.06 MPa. This study shows that adding 10% silica to the CLC mortar mixture can increase the compressive strength by 81.25% compared to mortar without silica fume.

Keywords: Cellular Lightweight Concrete, compressive strength, foam concrete, silica fume, LUSAS

1. Introduction

The building consists of components of the foundation, columns, beams, walls and roof. Walls are an essential part of a building. Most urban infrastructure in developing countries uses clay bricks as the primary material for building walls [1], [2], [3], [4]. The development of building materials science is overgrowing with the discovery of various kinds of mixed materials to increase the strength of these materials. Nowadays, the development of materials science for building construction is starting to be made with lightweight foam concrete [4], [5], [6], [7].

The need for foam concrete blocks encourages the emergence of innovations in brick making, one of which is the Cellular Lightweight Concrete (CLC) block. CLC block is made from cement, sand, water and foam. The mixture design of CLC mortar has many cavities, which cause the strength of the bonds between molecules to weaken [8]. Hence, CLC requires other additives to strengthen the molecular bonds.

Engineers used the CLC blocks for building wall materials because the CLC has a lower density than conventional clay bricks. The use of CLC blocks in buildings can reduce the load on the building. CLC is lighter than normal concrete and has low density, low cement and aggregate content in the mixture, thermal insulation, and sound suppression. Therefore, the CLC blocks have the advantage of saving time in installing building walls. In general, CLC has a larger size than clay bricks. The comparison of conventional clay brick and CLC blocks' size and shape is shown in Figure 1 [9], [10].

Figure 1. Cellular Lightweight Concrete blocks (a) size comparison with conventional clay brick (b) set of hardened CLC

The previous foam concrete studies with different addictive mixtures used recycled waste materials such as plastic wastes [11] and glass powder [12]. The researchers studied foam concrete with recycled glass powder as a substitute for some cement to increase compressive strength. The glass particle size must be smaller than 45 millimicrons to fill the pores of the foam concrete and increase adhesion to the foam concrete. The development of foam concrete research is growing because foam concrete's matrix structure is more substantial than lightweight concrete. The addition of materials to the mix design can reduce the porosity of the CLC and increase the density of the material. The addition of ground calcium carbonate (GCC) and glass fibre (GF) to the mortar mix increases the compressive strength and flexural strength of the concrete [13].

The development of building materials science is overgrowing with the discovery of various kinds of additives in concrete mixtures to increase the strength of building structures. Efforts to increase the strength of concrete materials have been carried out by [14] by replacing some cement with Granite Pulver (GP) of 5%, 10%, 15%, and 20% of the cement weight into the concrete mixture. The results showed an increase in concrete compressive strength of 1.6% and flexural strength of 6.8% due to a 15% Granite Pulver (GP) in the mixture. A mixture of foam concrete with polypropylene fibres [15], fly ash and silica fume [16] can produce high-strength lightweight concrete in building structures. Foam concrete with a density of 1000 to 1900 kg/m^3 can increase the compressive strength by 10 – 70 MPa [17].

The smallest particle of regular concrete is cement. Portland cement is a hydraulic cement produced by smoothing clinkers consisting of calcium silicates which are hydraulic additives in gypsum. The function of cement is to bind aggregate grains into a compact or dense mass and fill air cavities between aggregate grains by 10% of the volume of concrete [18]. Pozzolanic additives and very-fine particles can be used to reduce cement porosity. One of these additives is silica fume, a byproduct of combustion ash from making silicon metal or silicon alloy in an electric furnace [19]. In this study, the additional materials used were silica fume. According to previous studies, silica fume contains Silica (Si) elements. Silica (Si) can increase the strength of intermolecular bonds in foam concrete [20], [21], [22], [23].

Foaming agents are foam admixtures using a foam generator, producing a stable pre-foam in alkaline conditions [24]. Therefore it is suitable for making foam-containing mortars. The pre-foam added to the premixed mortar should be controlled to achieve the desired density. The mixture used is two parts of aggregate compared to 1 part of cement if the density is below 1000 kg/m^3. The foaming agent is a concentrated surfactant solution; hence, it should be dissolved with water before use. The mixing of air bubbles from the foaming agent into the mortar can cause air pores in the mortar. The use of the foaming agent in the foam concrete mixture could affect the stability of the foam, bulk density, microstructure and the resulting compressive strength [25], [26], [27], [28]. The reduction in pore size can affect the compressive strength of foam concrete [29], [30].

There are two foam agents for concrete admixture: synthetic and protein-based. The synthetic-based foam density is about 40 kg/m^3 and can expand to 25 times the initial volume. This foaming agent is very stable for density foam concrete above 1000 kg/m^3, with the ratio of foam and water being 1:19 [9]. Meanwhile, foam made from natural protein weights about 80 kg/m^3 can expand about 12.5 times its initial volume. This foam is relatively more stable and has a higher strength than synthetic foam. The ratio of foam and water is 1:33 to 1:39 [31], [32].

Process curing of CLC has two methods, namely wet curing and steam curing at atmospheric pressure. CLC is usually given a short wet curing period in the curing process, which is watered down, generally about 1 to 7 days and then allowed to dry on its own. Meanwhile, steam curing at atmospheric pressure of 50 to 80 degrees Celsius accelerates the hardening of CLC, shrinkage drying and movement of concrete moisture after drying atmospheric pressure steam for a maximum of 24 hours. Water in a concrete mixture has two functions, the first to allow chemical reactions that cause binding and hardening, and the second as a gravel, sand and cement mixture to make moulding easier. The water used must be free of harmful substances such as mud, clay, organic matter and organic acids, alkalis and other salts.

This study used silica fume as additional material for cellular-lightweight concrete. Silica fume is a densified dry powder micro silica admixture for portland cement concrete and mortars. Silica fume contains high levels of SiO_2 and is a very smooth, round shape, which has a diameter of 1/100 times the diameter of a cement [19], [23]. Silica fume is a pozzolanic material. In use, silica fume is a partial replacement for cement in a concrete mixture, 5% -15% of the total cement weight. Silica fume fills cavities between cement materials. The filling of holes in concrete has a significant impact on the compressive strength of the concrete. Silica fume is a pozzolan that can react with $Ca(OH)_2$ to produce $C_3S_2H_3$ as a source of concrete strength [33],[34].

Previous researchers have attempted to increase the strength of concrete with the addition of silica in the mix design [35], [36], [37], [38]. However, only a few studies discuss the addition of silica fume to increase lightweight bricks, especially cellular lightweight concrete (CLC), experimentally and numerically analysed using LUSAS finite element software [39]. Therefore, this study aims to identify the mechanical behaviour of CLC based on the proportion of silica fume substitution in the CLC mortar mixture. CLC is a porous concrete formed mechanically by adding a foaming agent. Many pores in the concrete can limit its strength, making CLC blocks more brittle than clay bricks. Therefore, it is necessary to add alternative materials so that the presence of these pores does not reduce the compressive strength of foam concrete.

2. Materials and methods

The research method examines aggregate properties consisting of several tests such as water content, volume weight, specific gravity, sieve analysis, silt content, and organic content. The research was initiated by testing the properties of fine aggregates at the Materials Testing Laboratory, Faculty of Engineering, University of Riau, Indonesia. The materials used in this study are Portland Composite Cement (PCC) cement type CEM I 42.5 N, fine aggregate (sand), water, foaming agent and silica fume.

In this study, PCC cement from Semen Padang Company, Indonesia. According to Indonesian Standard [18], PCC cement consists of limestone containing calcium oxide (CaO), clay containing silica oxide (SiO_2), aluminium oxide (Al_2O_3), iron oxide (Fe_2O_3) and gypsum, which serves to control hardening. Composite Portland cement is the result of mixing Portland cement powder with other inorganic powders. The inorganic materials include blast furnace slag, pozzolan, silicate compounds, and limestone, with a total inorganic content of 6% to 35% of the mass of composite portland cement.

The fine aggregate in this study used the natural river sand from the Kampar River, Riau Province, Indonesia. This research carried out is sieve analysis to determine the fine aggregate size that meets ASTM standards [40]. Table 1 shows the fine aggregate's physical properties and sieves analysis. Figure 2 shows the grain size distribution of the fine aggregates. According to [40], determining the gradation area and type of sand is based on the percentage passing the fine aggregate sieve. The sand in the gradation area was zone 2, sand with slightly coarse grains.

Table. 1 Sieve Analysis of Fine Aggregate

Size No.	Sieve Size (mm)	Weight retained (g)	Weight retained (%)	Cumulative % retained	Cumulative % passed
No. 4	4.75	15.51	1.60	1.60	98.40
No. 8	2.36	38.96	3.90	5.50	94.50
No. 16	1.18	85.20	8.50	14.0	86.00
No. 30	0.60	324.87	32.50	46.60	53.40
No. 60	0.30	390.21	39.20	85.80	14.20
No. 100	0.15	109.51	11.00	96.80	3.20
No. 200	0.075	27.67	2.80	99.50	0.50
PAN		4.59	0.500	100.00	0.00
Total		996.11	100	248.60	

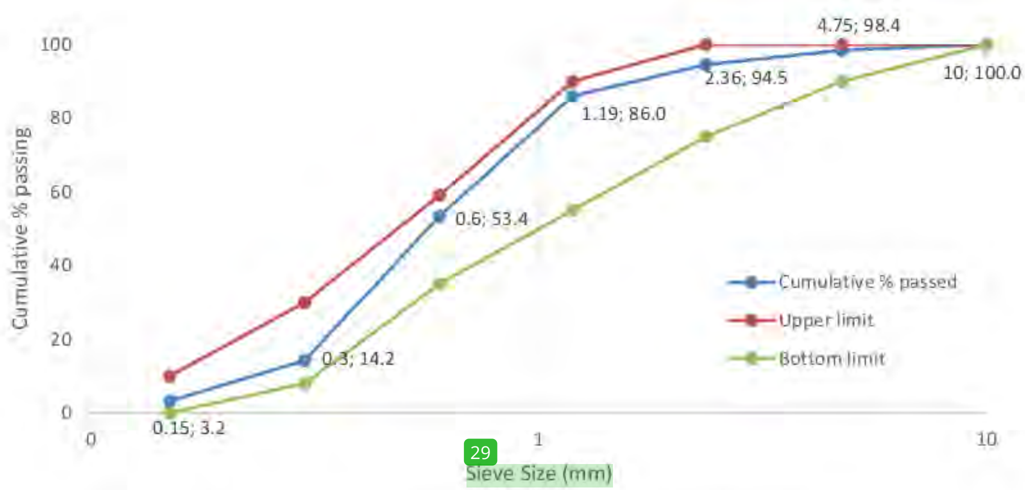

Figure. 2 Sieve Analysis Results of Fine Aggregate based on ASTM C33/C33M Standard limit

This study used silica fume from the Sika Indonesia factory in Bogor, Indonesia [41], which met ASTM C-1240 [42]. Meanwhile, the foaming agent as a foam-producing liquid refers to ASTM-C 869/C 969M-11 [31]. The foam and silica fume is used in the study, as shown in Figure 3.

Figure 3. CLC design mix material (a) foam (b) silica fume

The physical properties of sika fume are grey, powder form with a density of 0.65 kg/L and size of diameter particles less than 1 μm; about 100 times smaller than the average cement particle. The use of Sika fume will increase the capability of the concrete by reducing the permeability so that the durability of the concrete increases and improves strength bonding and fresh concrete stability, increasing resistance to carbonation and enhancing the concrete strength. Sika fume contains very fine reactive silicate dioxide. The advantage of this material is that it can improve internal cohesion and excellent water retention in fresh concrete and cause the concrete to be very flexible. Under conditions of hardened concrete, latently reactive silica fumes form chemical bonds with free lime. This chemical process makes cement much denser. Sika fume can improve the stability of green concrete, significantly improve durability, increase ultimate strength, increase abrasion resistance and reduce chloride penetration. In addition, Sika fume does not contain chlorides or other corrosion-inducing agents for steel; therefore, Sika fume can be used without any restrictions for reinforced and prestressed concrete construction [41]. Characteristics of Sika fume from Sika Indonesia Company as shown in Table 2.

Table. 2 Product Information of Sika Fume produced by Sika Indonesia Company [41]

Chemical Name	Silica Fume
Concentration	≥60% - ≤100%
Appearance/Color	Powder/Grey
Density	0.65 kg/L
Approval/Certificates	SikaFume® conforms to ASTM C-1240

Sika fume has an essential role in influencing concrete's chemical and mechanical properties. In terms of mechanical properties, geometrically, Sika fume fills cement cavities and causes the pore diameter to shrink, and the total pore volume is also reduced. In terms of chemical properties, the reaction is pozzolanic, in which Sika fume can react with lime which is released directly from cement. In the manufacture of high strength concrete, the use of Sika fume can increase the strength of concrete. Therefore the Sika fume particles can fill the pore structure of the cement paste and can react with calcium hydroxide ($Ca(OH)_2$) produced from the hydration process of water and cement. The secondary reaction that occurs between $Ca(OH)_2$ with silicon dioxide (SiO_2) can form calcium silicate hydrate (CaH), which can increase the strength of concrete to a higher level [9].

The CLC mortar consists of fine aggregate composition, water, PCC cement, foaming agents and silica fume. The added ingredients of silica fume used were 0%, 0.5%, 1%, 5%, 10% and 15% by weight of cement respectively. The tests were carried out at 3, 7, 14, 21 and 28 days after curing for three specimens every test. Planning the composition of the mixture used a ratio of composition 1 to 2 for cement and sand, and the ratio of water-cement is 0.5. The planned mixture density is 0.85 to 0.9 kg/L. Table 3 shows the composition of the CLC mortar consisting of cement, sand, foaming agent and silica fume (SF).

Table 3. Composition of foam concrete CLC

Composition (SF % by weight of cement)	Cement (kg)	Sand (kg)	Foaming Agent (kg)	Silica Fume (SF) (kg)
Silica fume 0% (SF0)	50.76	101.74	6.5	0
Silica fume 0.5% (SF0.5)	50.76	101.74	6.5	0.25
Silica fume 1% (SF1)	50.76	101.74	6.5	0.50
Silica fume 5% (SF5)	50.76	101.74	6.5	2.53
Silica fume 10% (SF10)	50.76	101.74	6.5	5.08
Silica fume 15% (SF15)	50.76	101.74	6.5	7.61

Maintaining the specimen is carried out so that the cement hydration process is ideal. The treatment in this study uses the air curring method to place the models in an area with open-air circulation. The maximum compressive strength value based on the silica fume composition in Table 3 is used as a material for making prototype CLC with a length of 60 cm, a width of 10 cm and a height of 20 cm.

Prototype CLC block is carried out by testing the free press using a loading frame and load cell. The function of the load cell is a load reader given to the CLC block as the model. The test is carried out by placing a vertical load on the specimen. Load measurements were carried out using a data logger until the CLC surface collapsed. The compressive strength test procedure for CLC foam concrete is as follows:

a. Preparation of the testing tools: loading frame, data logger, load cell, hydraulic actuator, hydraulic jack. Figure 4 shows the installation of test equipment for the CLC prototype.
b. The CLC specimen is weighed and placed in the loading frame on the pedestal plate.
c. The load cell is placed on the upper side of the CLC block; then, the testing tool is run by pumping the hydraulic jack so that the load cell gives a load to the test object; pumping continues until the CLC is destroyed and the maximum loading value is obtained. The compressive strength value has been stored in the data logger.

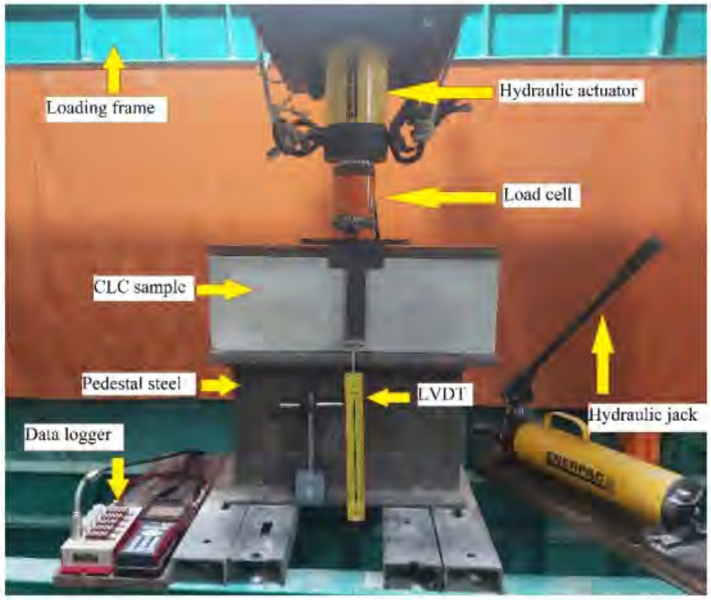

Figure. 4 Setting out CLC prototype test instrumentations on a loading frame

3. Result and Discussion

The material properties test results have met ASTM C136 [40], ASTM C40 [43] and ASTM C33 [44] standards. The results of testing for fine aggregate (sand) properties in sludge content testing, specific gravity testing, moisture content testing, volume weight testing, organic content testing and fineness modulus testing are shown in Table 4.

Table 4. Fine Aggregate Characteristic

No	Testing item	Result	Standard Range
1	Mud rate (%)	4.87	< 5
2	Specific Gravity		
	a. Apparent Specific Gravity	2.66	2.58-2.83
	b. Bulk Specific Gravity on Dry	2.63	2.58-2.83
	c. Bulk Specific Gravity on SSD	2.65	2.58-2.83
	d. Absorption (%)	5.49	2.0 – 7.0
3	Water content (%)	3.73	3 – 5
4	Volume weight (g/cm^3)		
	a. Solid condition	1576.61	1400-1900
	b. Dry condition	1415.45	1400-1900
5	Organic Impurities	No. 2	Max No. 3
6	Finess Modulus	2.49	1.5-3.8

The strength of CLC is influenced by several things: the characteristics of the lightweight concrete material, the cement water factor, the method of stirring, the composition of the mixture, the mixing machine used, and the treatment in the hardening process [8], [15], [17], [21], [23], [29], [45], [46], [47]. This study tested CLC for compressive strength at 3, 7, 14, 21, and 28 days after pouring the mixture into the mould for six compositions. Each test used three CLC samples with a height of 20 cm, a width of 10 cm and a length of 60 cm. The total of 90 specimens and a cross-section area is 60000 mm^2. Table 5 shows the compressive strength values for all compositions for 3, 7, 14, 21 and 28 days. The labelling of the specimens used in the experimental program, as shown on the label SF-D3-P0-S01, is explained as follows:
"SF-D3" shows a silica fume mixture in CLC three days after curing.
"P0" means the percentage of silica fume used in the mixture is 0%.
"S01" indicates the serial number of the first specimens.

Table 5. Compressive strength of CLC until 28 days of age

Design mix	Weight (kg)	Maximum loading (kN)	Compressive strength (MPa)	Code	Weight (kg)	Maximum loading (kN)	Compressive strength (MPa)
SF-D3-P0-S01	11.50	10.90	0.18	SF-D14-P5-S01	10.70	49.20	0.82
SF-D3-P0-S02	10.80	11.50	0.19	SF-D14-P5-S02	10.50	50.40	0.84
SF-D3-P0-S03	11.80	11.10	0.19	SF-D14-P5-S03	10.90	48.00	0.80
SF-D3-P0.5-S01	11.40	20.20	0.34	SF-D14-P10-S01	10.80	61.20	1.02
SF-D3-P0.5-S02	10.80	19.40	0.32	SF-D14-P10-S02	11.00	60.00	1.00
SF-D3-P0.5-S03	11.00	19.32	0.32	SF-D14-P10-S03	10.90	62.40	1.04
SF-D3-P1-S01	11.00	21.56	0.36	SF-D14-P15-S01	11.20	47.40	0.79
SF-D3-P1-S02	11.50	20.52	0.34	SF-D14-P15-S02	11.00	46.80	0.78
SF-D3-P1-S03	11.20	20.72	0.35	SF-D14-P15-S03	10.90	46.20	0.77
SF-D3-P5-S01	9.80	24.00	0.40	SF-D21-P0-S01	11.50	25.91	0.60
SF-D3-P5-S02	9.70	22.80	0.38	SF-D21-P0-S02	10.80	27.34	0.60
SF-D3-P5-S03	9.60	21.60	0.36	SF-D21-P0-S03	10.90	26.39	0.60
SF-D3-P10-S01	10.80	36.00	0.60	SF-D21-P0.5-S01	11.00	48.03	0.80
SF-D3-P10-S02	10.40	34.80	0.58	SF-D21-P0.5-S02	10.60	46.12	0.77
SF-D3-P10-S03	10.60	39.60	0.66	SF-D21-P0.5-S03	10.80	45.93	0.77
SF-D3-P15-S01	11.10	15.00	0.25	SF-D21-P1-S01	10.90	51.26	0.85
SF-D3-P15-S02	11.20	14.80	0.25	SF-D21-P1-S02	11.10	48.79	0.81
SF-D3-P15-S03	11.60	14.20	0.24	SF-D21-P1-S03	10.50	49.26	0.82
SF-D7-P0-S01	10.60	18.00	0.45	SF-D21-P5-S01	10.80	51.60	0.86
SF-D7-P0-S02	9.80	21.10	0.43	SF-D21-P5-S02	10.60	53.40	0.89
SF-D7-P0-S03	11.10	17.80	0.47	SF-D21-P5-S03	10.60	49.80	0.83
SF-D7-P0.5-S01	11.40	32.88	0.55	SF-D21-P10-S01	11.10	62.40	1.04
SF-D7-P0.5-S02	11.00	31.57	0.53	SF-D21-P10-S02	10.50	63.40	1.06
SF-D7-P0.5-S03	11.10	31.44	0.52	SF-D21-P10-S03	11.10	64.70	1.08
SF-D7-P1-S01	11.30	35.09	0.58	SF-D21-P15-S01	10.50	48.00	0.80
SF-D7-P1-S02	10.90	33.40	0.56	SF-D21-P15-S02	10.60	48.00	0.80
SF-D7-P1-S03	11.10	33.72	0.56	SF-D21-P15-S03	10.60	48.00	0.80
SF-D7-P5-S01	10.60	38.40	0.64	SF-D28-P0-S01	11.00	27.25	0.64
SF-D7-P5-S02	10.70	39.00	0.65	SF-D28-P0-S02	10.60	28.75	0.65
SF-D7-P5-S03	10.90	39.60	0.66	SF-D28-P0-S03	10.60	27.75	0.63
SF-D7-P10-S01	11.50	49.80	0.83	SF-D28-P0.5-S01	11.00	50.50	0.84
SF-D7-P10-S02	10.40	49.20	0.82	SF-D28-P0.5-S02	10.30	48.50	0.81
SF-D7-P10-S03	10.50	46.80	0.78	SF-D28-P0.5-S03	10.60	48.30	0.81
SF-D7-P15-S01	10.50	36.10	0.60	SF-D28-P1-S01	10.70	53.90	0.90
SF-D7-P15-S02	11.40	37.20	0.62	SF-D28-P1-S02	10.50	51.30	0.86
SF-D7-P15-S03	11.00	38.50	0.64	SF-D28-P1-S03	10.40	51.80	0.86
SF-D14-P0-S01	11.00	23.95	0.56	SF-D28-P5-S01	10.80	39.00	0.93
SF-D14-P0-S02	10.70	25.27	0.56	SF-D28-P5-S02	10.70	38.40	0.94
SF-D14-P0-S03	10.70	24.39	0.56	SF-D28-P5-S03	11.70	39.60	0.95
SF-D14-P0.5-S01	11.20	44.39	0.74	SF-D28-P10-S01	10.40	69.00	1.15
SF-D14-P0.5-S02	10.80	42.63	0.71	SF-D28-P10-S02	10.80	69.00	1.15
SF-D14-P0.5-S03	10.70	42.46	0.71	SF-D28-P10-S03	11.20	70.80	1.18
SF-D14-P1-S01	10.80	47.38	0.79	SF-D28-P15-S01	11.00	52.20	0.87
SF-D14-P1-S02	11.00	45.09	0.75	SF-D28-P15-S02	11.20	53.40	0.89
SF-D14-P1-S03	10.90	45.53	0.76	SF-D28-P15-S03	10.40	54.60	0.91

Figure 5 shows the experimental results; the compressive strength value of CLC with added silica fume 10% on admixture can reach 1.16 MPa at 28 days of the mortar age. Meanwhile, the compressive strength value of the CLC specimen without added silica fume resulted in 0.64 MPa.Thus there has been an increase in the compressive strength of CLC compared to before adding silica fume up to 81.25%, or almost twice the compressive strength of CLC without silica fume additives. The results are in line with the test results from previous researchers [20], [21], [23], [33], [48].

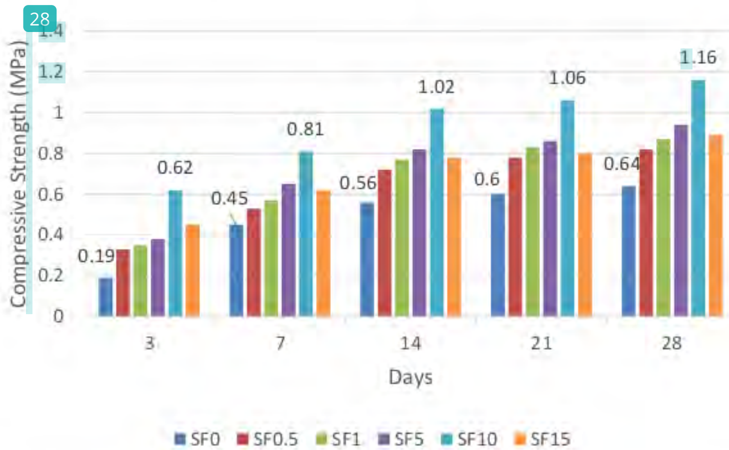

Figure. 5 Compressive strength of CLC with the added percentage of silica fume

The results of the CLC compressive strength test at 28 days in the laboratory show that more cracks occurred on the upper surface of CLC without using silica fume (SF0) compared to CLC using 10% Silica Fume (SF10). Figure 6 shows the visual form of CLC surface settlement. CLC specimen with a mixture without silica fume produces a more brittle surface, while the sample with added silica shows better quality.

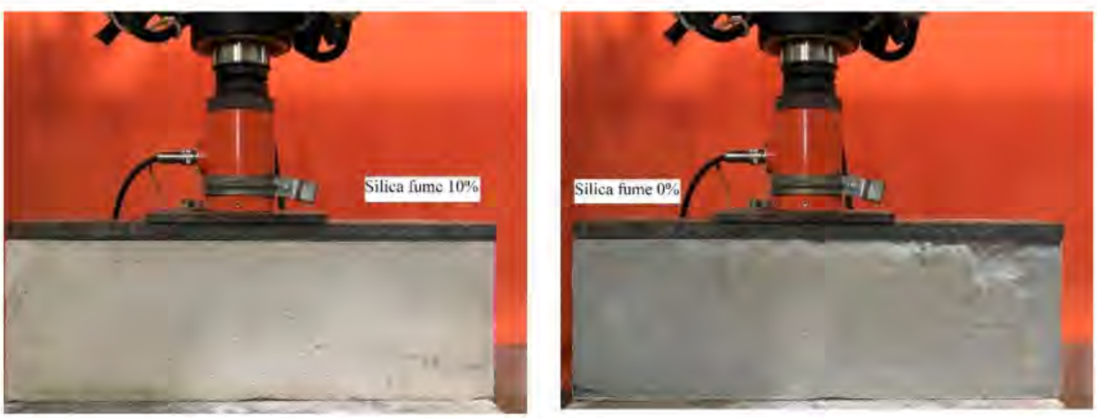

Figure 6. The CLC compressive strength test was after 28 days of curing (a) with silica fume 10% (b) without silica fume.

The mechanical testing results with a uniform load applied to the upper surface of the CLC specimen were validated by numerical analysis using the London University Structural Analysis System (LUSAS) Version 19 (V19), a finite element analysis software package [39]. Input parameters are used in the LUSAS analysis, as shown in Table 6.

Table 6 Input parameters of LUSAS V19 Finite Element Analysis.

Input Parameter		
Elastic Modulus	22971	N/mm^2
Poisson Ratio	0.15	
Density	841.389	kg/m^3

Table 7 compares the experimental results in laboratory and numerical analysis using LUSAS V19. The increase in the load given to the CLC specimen has resulted in a linear increase in the value of displacement, stress and strain.

Table 7 The comparison of laboratory experimental and numerical analysis of LUSAS V19.

	Experimental			Numerical		
Load kN	Displacement mm	Stress N/mm^2	Strain	Displacement mm	Stress N/mm^2	Strain
0.00	0.00	0.000	0.000	0.00	0.000	0.000
1.20	0.30	0.020	0.002	0.19	0.023	0.001
6.20	1.00	0.103	0.005	0.96	0.119	0.004
13.70	2.00	0.228	0.010	2.11	0.262	0.009
20.60	3.00	0.343	0.015	3.17	0.394	0.013
26.70	4.00	0.445	0.020	4.11	0.511	0.017
33.20	5.00	0.553	0.025	5.11	0.635	0.021
40.20	6.10	0.670	0.031	6.19	0.769	0.026
46.80	7.00	0.780	0.035	7.21	0.895	0.030
55.50	8.00	0.925	0.040	8.55	1.061	0.035
63.40	9.20	1.057	0.046	9.76	1.213	0.040

Numerical analysis shows the displacement of each node in the CLC model mesh, which is depicted by coloured contours. Each contour colour represents a different displacement value, as shown in Figure 7. The smallest displacement value is dark blue 1.02 mm, while the most significant displacement value is 9.20 mm, shown in orange. The most considerable displacement occurs at the top of the CLC surface, and the slightest settlement occurs at the bottom. This condition occurs because the upper part of the specimen receives the most significant load than the lower part.

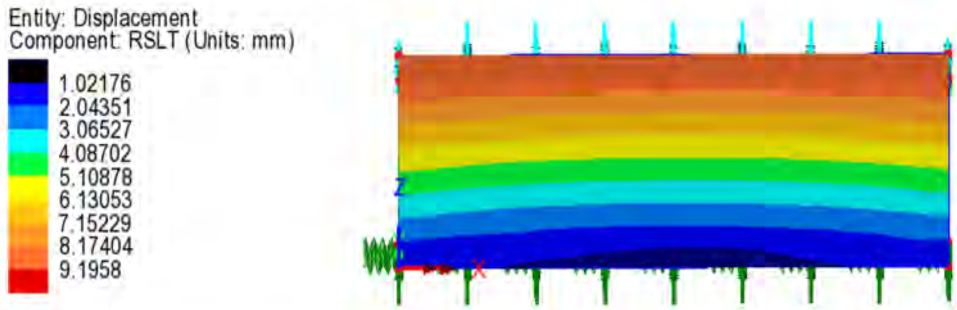

Figure 7. The nodes displacement due to uniform load at the upper surface of the CLC model

The numerical analysis results due to the loading of the CLC sample caused stress indicated by a coloured contour image on the surface of the CLC. Each colour represents a different stress value. Figure 8 shows the stress value on the CLC specimen. Based on Figure 8, the lower part of the CLC specimen is blue. This condition indicates that the area has the least stress. The slightest pressure value shown in blue-black is 0.955 N/mm^2, and the most significant stress value shown in orange is 1.06 MPa. The light green and yellow colour range values are 0.978 MPa to 1.011 MPa. This colour indicates that there has been a transition between the most significant stress and stress value so that the area shows an initial crack [49], [50].

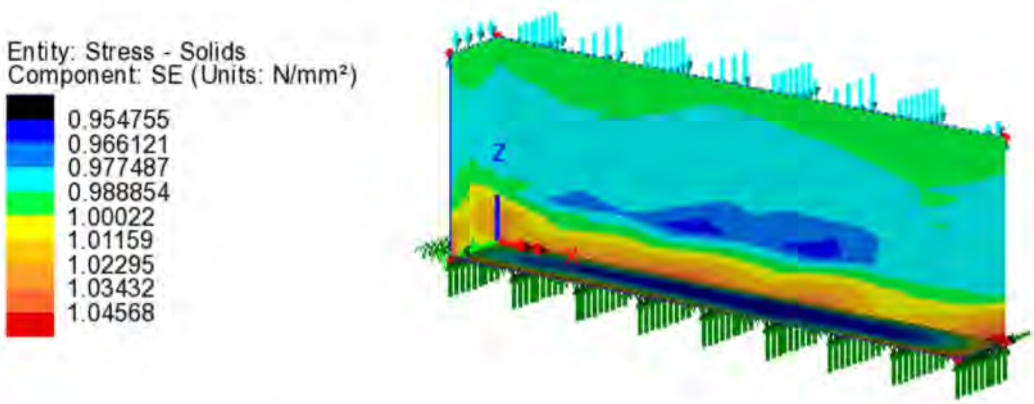

Figure 8. The stress contour on the surface of the CLC model due to uniform load

The uniform load applied to the top of the CLC model results in a strain represented by coloured contours. Each contour colour represents a different strain value, as shown in Figure 9. In the picture, the shape at the bottom of the CLC model is blue-black, indicating that this part is the area with the smallest strain value of 0.032. The most considerable strain value is shown in reddish yellow (orange) with a maximum strain value of 0.036. The light blue and yellow values, which are between 0.033 and 0.034, have been a transition between the most significant strain and strain so that the area shows an early crack [49], [50].

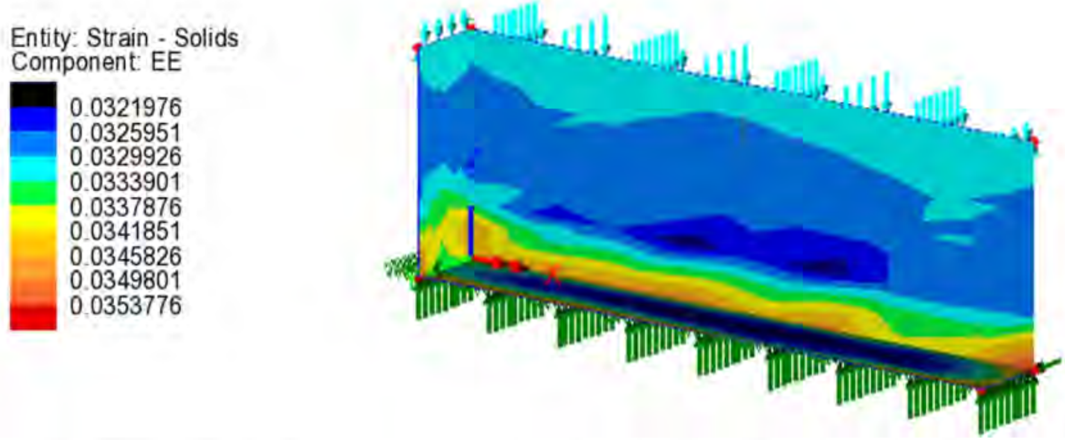

Figure 9. The strain contour on the surface of the CLC model due to uniform load

4. Conclusions

This study tested the CLC model specimen using an experimental program and numerical analysis using the finite element LUSAS V19 software. The study results describe the effect of the addition of silica fume based on the percentage of cement weight in the foam concrete mortar mixture to produce the best strength. Experimental studies in the laboratory used different percentages of silica fume ranging from 0% to 15% by weight of cement in foam mortar mixture. Based on the results obtained, the main conclusions can be drawn, namely:

1. The CLC block specimen without adding silica fume in the mortar mixture had a compressive strength value of 0.64 MPa. In comparison, the substitution of silica fume at 10% of the cement weight resulted in maximum compressive strength of 1.16 MPa at 28 days.
2. The substitution of silica fume by 10% of the weight of cement in the foam mortar mixture can increase the strength of foam concrete by 81.25% compared to without the replacement of silica fume.
3. The visual form of decreasing the surface of the CLC specimen with a mixture without silica fume resulted in a more brittle sample than CLC added with silica fume.
4. The highest compressive strength values for all percentages of silica fume composition were obtained from the specimens treated at room temperature for 28 days with 10% silica fume substitution.
5. Numerical analysis of LUSAS V19 describes the behaviour of surface settlement of the CLC model, stress and strain in the form of colour contours that represent the beginning of cracking in the model before it crumbles.

The substitution of silica fume above 20% by the weight of cement in the mortar mixture can cause a decrease in the strength of CLC foam concrete. Therefore, it is highly recommended to use the percentage of silica fume to manufacture CLC foam concrete in the range of 0.5% to 0.15% by weight of cement.

The Effect of Silica Fume Admixture on the Compressive Strength of the Cellular Lightweight Concrete

ORIGINALITY REPORT

9%	5%	6%	3%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	L Rumiyanti, S Wulandari, T Damayanti, S Sembiring, W Warsito. "Optimization of using Baturaja fly ash as a Portland Composite Cement (PCC) additive", Journal of Physics: Conference Series, 2020 Publication	1%
2	ore.exeter.ac.uk Internet Source	1%
3	R Suryanita, H Maizir, Ismeddiyanto, R Andriano, R Arditama. "Experimental study and numerical analysis of flexural behaviour of post-fire reinforced concrete beam", IOP Conference Series: Materials Science and Engineering, 2019 Publication	<1%
4	U Jusi, H Maizir, A Fadil. "The effect of adding silica fume for lightweight concrete brick in terms of strength criteria", IOP Conference Series: Earth and Environmental Science, 2021 Publication	<1%

5	Qasim S. Khan, M. Neaz Sheikh, Timothy J. McCarthy, Mehdi Robati, Mark Allen. "Experimental investigation on foam concrete without and with recycled glass powder: A sustainable solution for future construction", Construction and Building Materials, 2019 Publication	<1 %
6	Wiku A. Krasna, Rijali Noor, Denny D. Ramadani. "Utilization of Plastic Waste Polyethylene Terephthalate (Pet) as a Coarse Aggregate Alternative in Paving Block", MATEC Web of Conferences, 2019 Publication	<1 %
7	"Smart Technologies for Sustainable Development", Springer Science and Business Media LLC, 2021 Publication	<1 %
8	citeseerx.ist.psu.edu Internet Source	<1 %
9	garuda.kemdikbud.go.id Internet Source	<1 %
10	I L K Wong. "Effect compressive strength and split tensile strength of concrete using aggregate from Tana Toraja district with fly ash substitution", IOP Conference Series: Earth and Environmental Science, 2021 Publication	<1 %

11	core.ac.uk Internet Source	<1%
12	www.chinamicrosilica.com Internet Source	<1%
13	Submitted to Universiti Malaysia Sarawak Student Paper	<1%
14	Abdulaziz A. Bubshait, Bassam M. Tahir, M. O. Jannadi. "Use of microsilica in concrete construction", Building Research & Information, 1996 Publication	<1%
15	H Maizir, R Suryanita, R Arditama. "Study on performance of lightweight concrete bricks with a ratio of sand and cement composition", IOP Conference Series: Materials Science and Engineering, 2019 Publication	<1%
16	Submitted to Nottingham Trent University Student Paper	<1%
17	mafiadoc.com Internet Source	<1%
18	soa.utexas.edu Internet Source	<1%
19	www.mdpi.com Internet Source	<1%

20	iugspace.iugaza.edu.ps Internet Source	<1%
21	Safwan A. Khedr, Mohamed Nagib Abou - Zeid. "Characteristics of Silica - Fume Concrete", Journal of Materials in Civil Engineering, 1994 Publication	<1%
22	Y.H. Mugahed Amran, Rayed Alyousef, Hisham Alabduljabbar, M.H.R. Khudhair et al. "Performance properties of structural fibred-foamed concrete", Results in Engineering, 2020 Publication	<1%
23	Zahra Bouramdane, Abdellah Bah, Mohammed Alaoui, Nadia Martaj. "Numerical analysis of thermoacoustically driven thermoacoustic refrigerator with a stack of parallel plates having corrugated surfaces", International Journal of Air-Conditioning and Refrigeration, 2022 Publication	<1%
24	josbrouwers.bwk.tue.nl Internet Source	<1%
25	repository.futminna.edu.ng:8080 Internet Source	<1%
26	www.matec-conferences.org Internet Source	<1%

27	Qiang Song, Jiuwen Bao, Shanbin Xue, Peng Zhang, Mu Shining. "Collaborative disposal of multisource solid waste: Influence of an admixture on the properties, pore structure and durability of foam concrete", Journal of Materials Research and Technology, 2021 Publication	<1 %
28	downloads.hindawi.com Internet Source	<1 %
29	espace.curtin.edu.au Internet Source	<1 %
30	repository.uwl.ac.uk Internet Source	<1 %
31	www.ejge.com Internet Source	<1 %

Exclude quotes	Off	Exclude matches	Off
Exclude bibliography	Off		