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Civil Engineering Journal

Vol. 4, No. 9, September, 2018

The Effect of Styrofoam Artificial Lightweight Aggregate (ALWA) on Compressive Strength of Self Compacting Concrete (SCC)

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Received 21 July 2018; Accepted 12 September 2018

Abstract

Self-compacting concrete (SCC) is a fresh concrete that is able to flow and fill up the formwork by itself without the need of a vibrator to compact it. One of the reasons that causes the damage of a building structure during an earthquake is the heavy weight of its structural members which are from the high density of the material used such concrete material. Lightweight aggregate is one of the solutions to reduce the weight of the structure. Therefore, the SCC using the artificial lightweight aggregate (ALWA) is one of the solutions to reduce the self-weight (dead load) of a structure. This research was conducted to investigate the impact of the use of ALWA in conventional concrete and SCC in terms of its compressive strength and modulus of elasticity. To study the impact of the use of ALWA in SCC, several variation of percentage of ALWA as a substitution to the natural coarse aggregate was examined. The proportions of ALWA as a replacement to the coarse aggregate were 0%, 15%, 50%, and 100%. The test specimens were the cylindrical concrete of 200 mm in height and 100 mm in diameter for both compressive strength and modulus of elasticity tests. The results of the compressive strength test indicated that the higher the percentage of ALWA used in SCC, the lower the compressive strength of the concrete. The addition of ALWA as a substitution to the natural coarse aggregate to conventional concrete and SCC was found optimum at 15% replacement with the compressive strength of conventional concrete and SCC of 21.13 and 28.33 MPa, respectively. Whereas, the modulus of elasticity of the conventional concrete and SCC were found to be 20,843.99 and 23,717.77 MPa, respectively.

Keywords: Artificial Lightweight Aggregate; Compressive Strength; Modulus of Elasticity; Self-Compacting Concrete; Styrofoam.

1. Introduction

Concrete is one of the options for structural materials and its use is the most popular in the construction among others [1-3]. However, its heavy weight brings another issue to the buildings particularly in terms of construction and its vulnerability to earthquake disaster. An earthquake is one of the natural disasters that can cause severe damage to the building structures [4-6]. The earthquake force received by the building structure is directly proportional to the weight of the corresponding building. Lightweight concrete is used as an alternative to reduce the self-weight of the building structure such that it can mitigate the damage of the building structures due to the severe earthquakes. Therefore, the need of lightweight materials becomes increasingly popular and required urgently for various applications in the modern construction technology for structural members [7, 8]. This is due to the various advantages that can be obtained from the use of lightweight concrete material, such as smaller density of concrete resulting in lower self-weight of the structural members [9, 10]. To be categorized as lightweight concrete, its density should be less than 1840 kg/m^3 [11].

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http://dx.doi.org/10.28991/cej-03091143

Besides, the structural members must still conform the requirements particularly on the compressive and tensile strengths for the lightweight concrete when used for structural purposes.

Lightweight concrete is known for good performance and durability when it was made properly during the mixing process. In the structural applications, the weight of concrete structures is very important because it also forms the total load of the buildings. The self-weight reduction by using the lightweight concrete can significantly reduce the gravity load and further, the mass of seismic inertia, thereby also reducing the size of structural members such as slabs, beams and columns as well as foundation at the end [12-15]. The reduction also affects the use of reinforcement in the design. Less reinforcement is needed due to the lower stresses or internal forces occurred in structural members [16-19]. Lightweight aggregate concrete has better strain capacity, lower thermal expansion coefficient, and better sound isolation characteristics due to the presence of air cavities in the lightweight aggregate [20].

In concrete construction work, especially conventional reinforced concrete construction, one of the most absolute work to do is concrete compaction or vibration. The purpose of compaction is to minimize the air trapped in the fresh concrete to provide the homogeneous concrete. Incomplete compaction on reinforced concrete members can decrease the compressive strength and durability of concrete that can cause the corrosion of the steel reinforcement in concrete. One of the solutions to resolve that issue is to use the self-compacting concrete or self-consolidating concrete (SCC) or also known as the flow concrete. SCC can flow under its own weight so it can fill up the formwork and reach its highest density [7]. In addition, the artificial lightweight aggregate (ALWA) was introduced in SCC to produce the self-compacting lightweight concrete (SCLC). The ALWA used in SCC was the Expanded Polystyrene (EPS) aggregate. It substitutes the natural coarse aggregate by 10%, 15%, 22.5%, and 30% of the total volume of concrete. The results showed that the greater EPS used in SCC, the smaller density as well as the compressive strength of concrete [21]. The EPS aggregate is a low density material and it does not absorb the mixing water [22]. Concrete with lightweight aggregate is an excellent solution to reduce the self-weight (dead load) of the structures. The application of ALWA in SCC provides several advantages in terms of cost and construction time, since it can eliminate the compaction process and better workability [23].

Based on the styrofoam lightweight aggregate concrete research which has been conducted previously by several researchers, it is known that the compressive strength of concrete decreases with the addition of styrofoam percentage in concrete as a substitution to the natural coarse aggregate. This is due to that the styrofoam is weaker compared to the natural coarse aggregate such as crushed stone [24]. Styrofoam grain can be formed into different specific sizes as required and it depends on the temperature during the evaporation process. The higher the temperature, the larger size and the more likely the occurrence of microscopic cracks [25]. The styrofoam was dissolved with the acetone solution and then formed into granules such that it resembles the shape of the natural coarse aggregate. After resembling the coarse aggregate then it was coated with the paste. This study was to investigate the use of styrofoam ALWA in SCC and their mechanical properties such as the compressive strength and modulus of elasticity as well as the characteristics of the fresh SCC such as its workability by slump or flow test and the density of using ALWA.

2. Experimental Program

2.1. Materials

The hydraulic cement used in this research was the Type I Portland cement or Ordinary Portland Cement (OPC). Coarse aggregate used Artificial Lightweight Aggregate (ALWA) was made from styrofoam material, acetone solution, and mortar. The composition ratio of acetone solution and styrofoam material was 1:1.9. After the ALWA grain was formed, then it was coated by the mortar with the ratio of sand: cement: water: adhesive of 1:1:0.25:0.025. The result of the styrofoam ALWA produced by the process is shown in Figure 1.

(a) pre-coated **(b) post-coated**

Figure 1. Styrofoam ALWA

Crushed stone in this research was also used in SCC as the partial natural coarse aggregate which was partly or completely replaced by the styrofoam ALWA. Fine aggregate used was the natural sand. The superplasticizer was used to improve the workability of the concrete mixture.

2.2. Mixture Proportion

The mixture proportion was obtained from the mix design. The calculation depends on the data which was observed in the laboratory work to perform more accurate calculation based on the actual conditions of the constituent materials of concrete such as the density, specific gravity, coarse and fine aggregate sieve analysis or gradation. The various compositions of concrete mixture prepared for comparisons in the study are given in Tables 1 and 2.

Table 1. Mix design of conventional concrete

Materials	Mass (kg/m^3)			
	0%	15%	50%	100%
Cement	475	475	475	475
Water	190	190	190	190
Fine Aggregate	1033	1033	1033	1033
Coarse Aggregate	689	585	344	-
ALWA	-	55	183	367

Table 2. Mix design of self-compacting concrete (SCC)

Materials	Mass (kg/m^3)			
	0%	15%	50%	100%
Cement	475	475	475	475
Water	190	190	190	190
Fine Aggregate	1033	1033	1033	1033
Coarse Aggregate	689	585	344	-
ALWA	-	55	183	367
Superplasticizer	2.846	2.846	2.846	2.846

3. Test Methods

In this research, the specimens used for compressive strength and modulus of elasticity tests were the concrete cylinders with the diameter of 100 mm and the height of 200 mm as many. Twelve cylinders of conventional concrete and twelve cylinders of SCC were prepared and they were cured until 28 days of age before the tests. The fresh concrete test for conventional concrete is the slump test, whereas for SCC, it consists of the flow, T500 slump time, V-funnel, and L-box tests. Testing of compressive strength and modulus of elasticity of concrete were performed with the loading rate conforming ASTM C39/C39M-18 [26] using a Universal Testing Machine (UTM). The machine used to measure the compressive strength of concrete as well as the stress and strain values such that the modulus of elasticity of the concrete can be calculated. The load and displacement were measured using the load cell and transducer, respectively. Data logger was used to read the data from the instrument and a computer system used to record the data from the data acquisition. For each composition, i.e. 0%, 15%, 50%, and 100% ALWA replacement, used three cylinder specimens to provide the representative average values.

3.1. Slump Flow Dan T500 Slump Time Tests

The objectives of these tests are to measure the flow ability of SCC without any obstacles. T500 slump time is the time required by the viscosity flow of SCC to spread with the diameter of 500 mm. The slump flow and T500 slump time tests conform EFNARC [27]. The shape and size of the baseplate used for these tests can be seen in Figure 2.

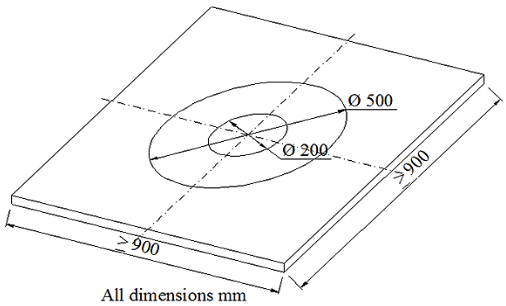


Figure 2. Baseplate for slump flow test

3.2. V-funnel Test

The V-funnel test is to determine the viscosity and filling ability of the SCC. The test is to define the time required by the SCC to flow out from the V-funnel. The test is not suitable when the coarse aggregate size is greater than 20 mm. The V-funnel test conform EFNARC [27]. The shape and dimensions of the apparatus for the test is shown in Figure 3.

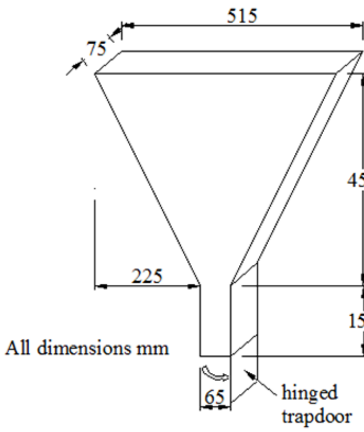


Figure 3. V funnel

3.3. L-box Test

The L-box test is used to measure the passing ability of SCC through the spaces between bars or obstacles without experiencing segregation or clogging. The test also conforms EFNARC [27]. The shape and dimensions of L-box can be seen in Figure 4.

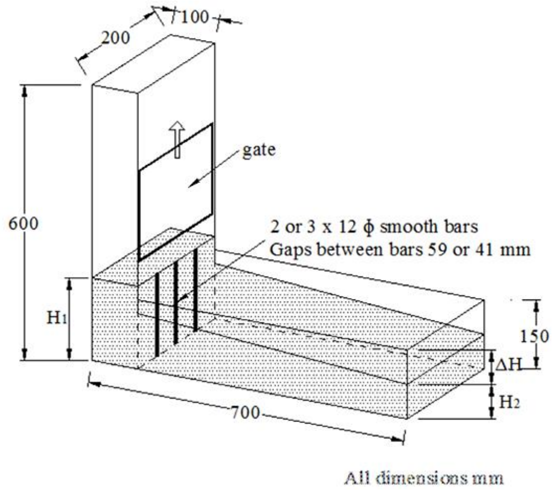


Figure 4. L-box

To calculate the passing ability, the following equation can be used:

$$PA = H_2/H_1 \quad (1)$$

Where:

PA = passing ability.

H_1 = height of fresh concrete in box I (mm).

H_2 = height of fresh concrete in box II (mm).

3.4. Sieve Segregation Resistance Test

The sieve segregation resistance test is to measure the resistance of SCC against the segregation of coarse aggregate. The sieve segregation resistance test refers to EFNARC [27]. The segregated or separated portion of the SCC can be calculated using the following equation:

$$SR = (W_{ps} - W_p)/W_c \times 100\% \quad (2)$$

Where:

SR = segregated portion (%).

Wps = weight of fresh concrete passing the sieve (gr).

Wp = weight of the sieve (gr).

W_c = weight of the fresh concrete on the sieve (gr).

4. Results and Discussion

4.1. Testing of Materials

The materials used in this research included the natural coarse and fine aggregates besides the styrofoam ALWA. The test results of the materials, such as sand, crush stone, and the styrofoam ALWA are given in Table 3.

Table 3. Testing of materials

Material Tests		Aggregate		
		Sand	Crush stone	ALWA
Unit weight (gr/cm³)	Rodding	1.475	1.483	0.783
	Jigging	1.258	1.317	0.715
Density (gr/cm³)		2.679	2.669	1.190
Absorption (%)		1.590	1.145	-
Sieve analysis (fine modulus)		3.794	6.559	-
Materials finer than 75-µm (%)		3.630	0.395	-
Total evaporable moisture (%)		4.384	0.644	-
Abrasion (%)		-	21.284	-
Impact		-	11.4	24.40
Organic impurities		Category 3	-	-

All the tests conducted for the fine and coarse aggregates as well as ALWA, namely unit weight (gr/cm³), density (gr/cm³), absorption (%), sieve analysis (fine modulus), materials finer than 75-µm (%), total evaporable moisture (%), abrasion (%), impact, and organic impurities, indicate that all the results satisfy the requirements to be used as concrete materials. For the gradation of sand and crush stone are shown in Figures 5 and 6.

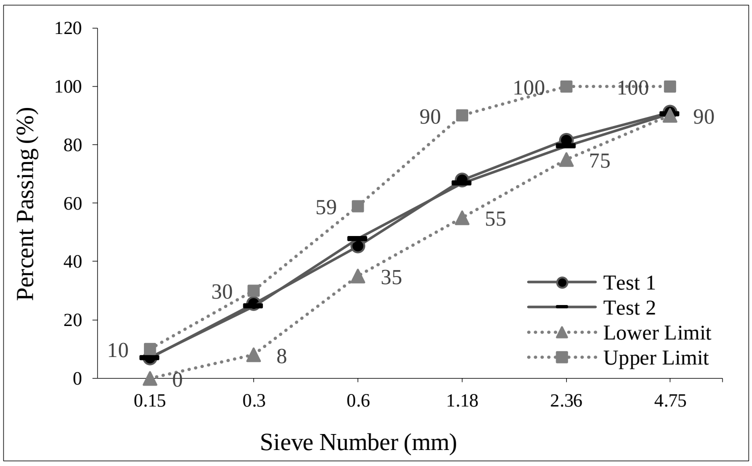


Figure 5. Gradation of sand (Zone II)

In the test, the sand used for SCC was found within zone II (medium category sand). Based on ASTM C136/C136M-14 [28], a good aggregate is an aggregate that falls within a predetermined sieve. From Figure 5, it can be seen that the sand used has met the requirements. The limit of fine modulus value for fine aggregate is 1.5 to 3.8. From the test, it was obtained that the fine modulus values from Tests 1 and 2 were 3.79 and 3.80, respectively. This indicates that the fine modulus has satisfied the requirements.

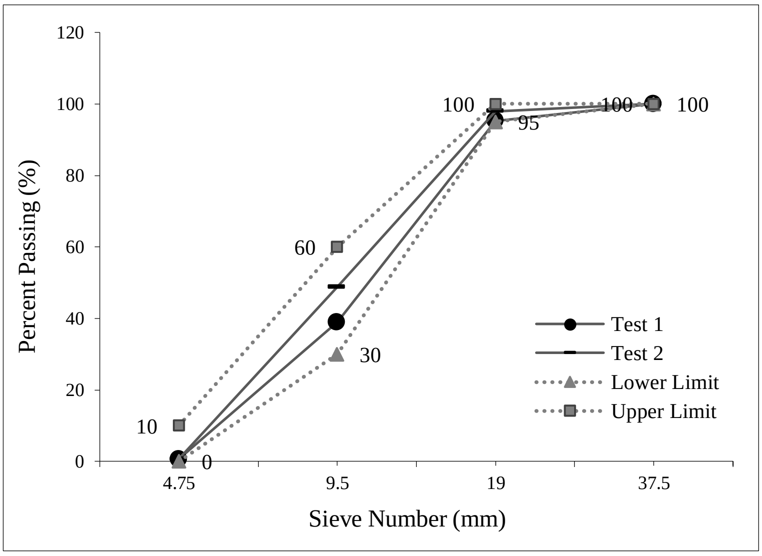


Figure 6. Gradation of coarse aggregate with maximum size of 20 mm

The coarse aggregate complies with the maximum sieve of 20 mm [28]. The limit of fineness modulus for the coarse aggregate is between 6.0 and 7.1. From the test results, the fineness modulus for Tests 1 and 2 were found to be 6.62 and 6.50, respectively. Hence, the fineness modulus of the course aggregate has satisfied the requirements.

4.2. Testing of Fresh Concrete Slump

The fresh concrete was observed by using the slump test for its workability. The slump test was conducted to obtain the slump value which can be used as a benchmark of the concrete mixture in association with the level of workability. The results of fresh concrete test for each mixture are listed in Tables 4 and 5.

Table 4. Slump of conventional concrete

Mixture	Slump (cm)
C0	2.5
C15	2.5
C50	2
C100	1.7

Replacement of the natural coarse aggregate with the styrofoam ALWA in the conventional concrete did not improve the workability. This can be seen from the slump test results that was less than that of the conventional concrete without the styrofoam ALWA. While on SCC concrete for slump flow test results can be seen in Table 5.

Table 5. Slump flow and T_{500} slump time tests of SCC

Mixture	Slump flow (cm)	T_{500} Slump time (s)
SCC0	66	2.15
SCC15	65	2.85
SCC50	90	1.67
SCC100	76	1.92

The results of the slump flow tests of specimens SCC0 and SCC15 indicated that the addition of 15% of the styrofoam ALWA can reduce the diameter of slump flow. However, the results of both tests still satisfied the EFNARC [27] where the limit of the allowable slump flow is between 65 and 80 cm. The results of slump flow tests of specimens SCC50 and SCC100 failed to conform the standard due to the segregation occurred between the coarse and fine aggregates. For the results of the T_{500} slump time of SCC50 and SCC100, both are not eligible since the EFNARC [27] requires the fresh SCC to have the T500 slump time value from 2 to 5 seconds. For more details, results of the slump flow tests of each SCC are shown in Figure 7.

Specimen SCC0

Specimen SCC15

Specimen SCC50

Specimen SCC100

Figure 7. Results of slump flow tests of SCC

The results of the V-funnel, L-box, and Segregation Resistance Tests for fresh SCC of all specimens are listed in Table 6.

Table 6. V-funnel, L-box, and segregation resistance test results

Mixture	V-funnel (s)	L-box (s)	Segregation Resistance (%)
SCC0	6.05	0.91	11.39
SCC15	7.05	0.86	14.53
SCC50	10.44	0.21	26.53
SCC100	Not flowing	Not flowing	33.90

The results of all these tests refer to the EFNARC [27]. From the results of V-funnel test, it was found that the concrete mixture with 0%, 15%, and 50% replacement meet the requirements since the concrete was able to flow through the V funnel and took times of 6 to 12 seconds. While, for the L-box test only 0% and 15% replacement mixtures satisfied the requirements in which the values of H_2/H_1 are in between 0.8 and 1 [27].

4.3. Density of Concrete

The densities of both conventional concrete and SCC shown in Table 7 are the average densities of six cylinders from each mix design.

Table 7. Density of conventional concrete and SCC

Specimen	Density (kg/m^3)
C0	2376.71
C15	2339.58
C50	2244.08
C100	2069.01
SCC0	2435.07
SCC15	2344.88
SCC50	2323.66
SCC100	2249.39

The relationship between the density of conventional concrete and SCC and the percentage of styrofoam ALWA replacement is shown in the graphical manner in Figure 8.

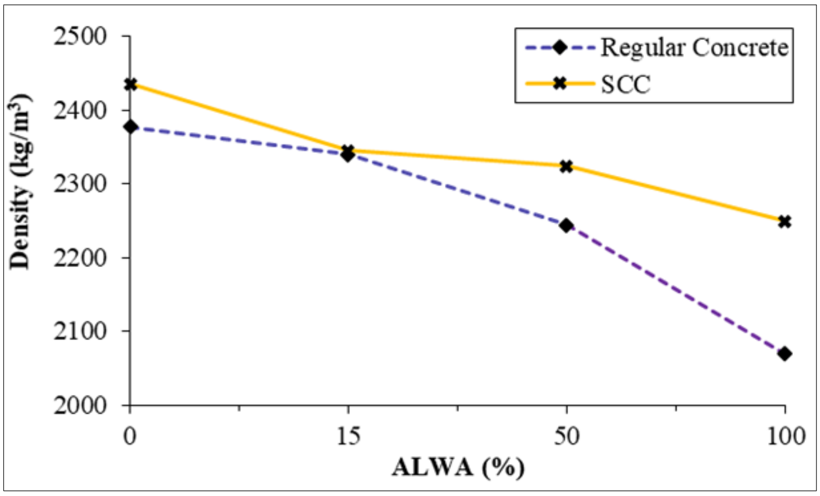


Figure 8. The relationship between the density of conventional concrete and SCC and the percentage of styrofoam ALWA replacement

From Figure 8, it can be seen that the higher percentage of the styrofoam ALWA used in concrete the lower its density. This was occurred due to the specific gravity of the styrofoam ALWA is smaller when compared to the specific gravity of the natural crush stone, i.e. the specific gravity of the styrofoam ALWA was only 1.190, while the specific gravity of the natural crush stone was about 2.669. According to the ASTM C330/C330M-17 [29], the concrete can be classified into lightweight concrete if its density does not exceed 1840 kg/m^3. From the results of density measurement shown in Table 6, it can be seen that all the conventional concrete and SCC do not conform the requirement since their densities are above 1840 kg/m^3. However, the density of conventional concrete with 100% styrofoam ALWA replacement to the natural coarse aggregate can reduce the density of concrete up to 13.21% lower than the conventional concrete without styrofoam ALWA.

4.4. Compressive Strength

Testing of compressive strength on conventional concrete were carried out when the concrete was at 28 days of age. The test procedure for compressive strength test is based on the ASTM C39/C39M-18 [26]. The results of compressive strength tests on conventional concrete are given in Table 8.

Table 8. Compressive strengths of conventional concrete

Specimen	Compressive strength (MPa)
C0	22.71
C15	21.13
C50	19.39
C100	16.56

From Table 8, it can be seen that the higher the percentage of styrofoam ALWA replacement in concrete, the lower its compressive strength. The optimum styrofoam ALWA replacement to the natural coarse aggregate in concrete was at about 15% which produced the highest compressive strength of 21.13 MPa.

In accordance with the ACI 318M-14 [11], the minimum compressive strength required for seismic-resistant concrete structures is 21 MPa, whereas for the structural concrete is 17 MPa. From the results of the compressive strength tests of the conventional concrete, it can be found the optimum percentages of styrofoam ALWA that conform both minimum values of concrete compressive strengths (i.e. 21 and 17 MPa) for seismic-resistant concrete structures and structural concrete, respectively [30]. The correlation between the compressive strength of conventional concrete and the percentage of styrofoam ALWA replacement is shown in Figure 9.

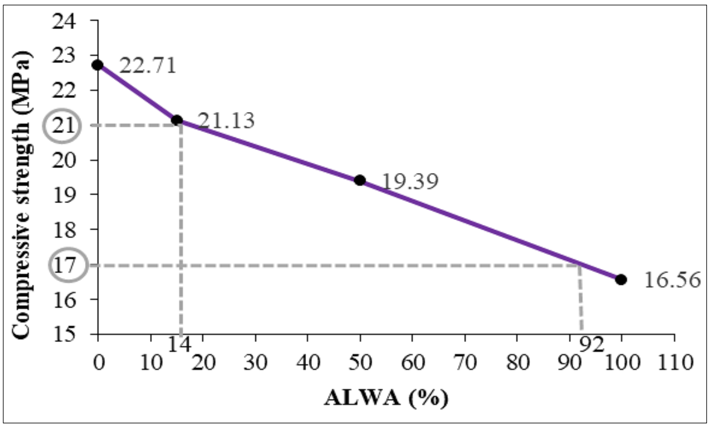


Figure 9. The relationship between the compressive strength of conventional concrete and the percentage of styrofoam ALWA replacement

The results of the compressive strength tests of conventional concrete with styrofoam ALWA were plotted to form a curve shown in Figure 9. It can be seen that the 21 MPa compressive strength can be achieved when 14% styrofoam ALWA was used as a replacement to the natural coarse aggregate. To achieve the 17 MPa compressive strength of concrete, higher percentage of styrofoam ALWA as much as 92% can be applied.

Testing of compressive strength on self-compacting concrete (SCC) were carried out when the concrete was at 28 days of age. The test procedure for compressive strength test is based on the ASTM C39/C39M-18 [26]. The results of compressive strength tests on SCC are listed in Table 9. The crack and failure patterns of conventional concrete for specimens C0, C15, C50, and C100 are shown in Figure 10.

Table 9. Compressive strengths of SCC

Specimen	Compressive strength (MPa)
SCC0	33.25
SCC15	28.33
SCC50	21.24
SCC100	18.99

Specimen C0

Specimen C15

Specimen C50

Specimen C100

Figure 10. Failure and crack patterns of conventional concrete

From Figure 10, it can be seen the crack and failure patterns of specimens C0, C15, and C100 can be categorized as shear type, whereas specimen C50 is in the category of cone-shaped and shear type pattern. The four test specimens are considered conforming the requirements of ASTM C39/C39M-18 [26]. For the results of the compressive strength test on SCC can be seen in Table 9.

Based on Table 9, it can be seen that the increase of styrofoam ALWA replacement resulting to the decrease of compressive strength of concrete. The highest compressive strength of SCC with styrofoam ALWA was attained at about 15% replacement with the corresponding compressive strength value of 28.33 MPa.

The relationship between the compressive strength of SCC and the percentage of styrofoam ALWA replacement is given in Figure 11. The optimum percentage of styrofoam ALWA replacement to the natural coarse aggregate for SCC can also be found from the correlation generated in Figure 11 to achieve the minimum compressive strength requirements for both seismic-resistant concrete structures (21 MPa) and structural concrete (17 MPa) [31].

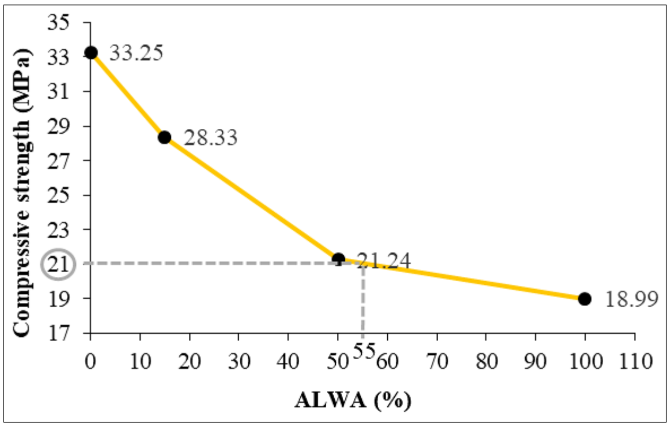
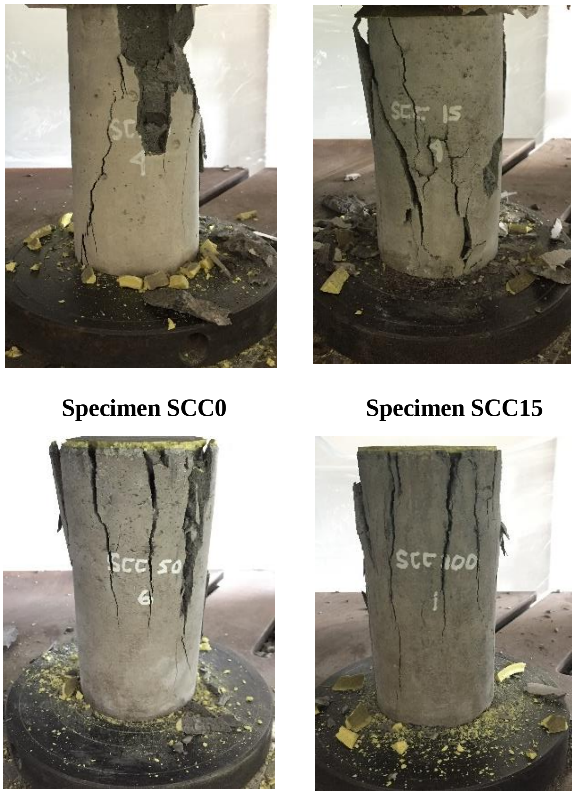


Figure 11. The relationship between the compressive strength of SCC and the percentage of styrofoam ALWA replacement

From Figure 11, it can be found that the percentage of styrofoam ALWA replacement to achieve 21-MPa concrete is about 55%, whereas to achieve the compressive strength requirement to satisfy the structural concrete of 17 MPa [32,33], 100% styrofoam ALWA can be used to replace all the natural coarse aggregate. The crack and failure patterns of SCC for specimens SCC0, SCC15, SCC50, and SCC100 can be seen in Figure 12.



Specimen SCC0 **Specimen SCC15**

Specimen SCC50 **Specimen SCC100**

Figure 12. Failure and crack patterns of SCC

From Figure 12, it is shown that the crack and failure patterns of specimens SCC0 and SCC15 can be classified as shear-type pattern whereas for specimens SCC50 and SCC100 can be defined as the columnar-type pattern. The crack and failure patterns of allfour specimens satisfied the requirements as per ASTM C39/C39M-18 [26].

4.5. Modulus of Elasticity of Concrete

The test results of modulus of elasticity of conventional concrete and SCC are listed in Tables 10 and 11.

Table 10. Modulus of elasticity of conventional concrete

Specimen	Stress (MPa)	Strain	Modulus of Elasticity (MPa)
C0	10.221	0.00046	22,031.53
C15	9.510	0.00046	20,843.99
C50	8.727	0.00045	19,286.57
C100	7.451	0.00043	17,332.46

Table 11. Modulus of elasticity of SCC

Specimen	Stress (MPa)	Strain	Modulus of Elasticity (MPa)
SCC0	14.963	0.00058	25,998.72
SCC15	12.750	0.00054	23,717.77
SCC50	9.559	0.00051	18,954.01
SCC100	8.544	0.00049	17,346.44

According to the ACI 318M-14 [11], the modulus of elasticity of concrete can be computed by dividing the stress value ($0.45f_c'$) with the strain corresponding to 45% of its peak stress. From Tables 10 and 11, it can be seen that the higher percentage of styrofoam ALWA used in concrete the smaller the strain value. The correlation between the modulus of elasticity and the percentage of styrofoam ALWA replacement is presented in Figure 13.

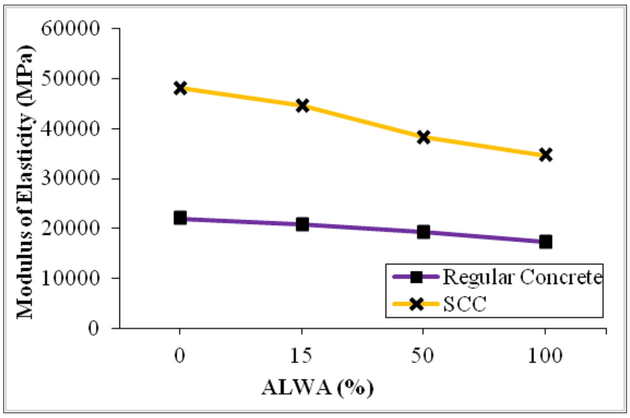


Figure 13. The relationship between the modulus of elasticity of concrete and the percentage of styrofoam ALWA replacement in both conventional concrete and SCC

From Figure 13, it can be seen that the more styrofoam ALWA replacement in both conventional concrete and SCC, the smaller the modulus of elasticity of concrete. The modulus of elasticity of SCC is higher than the modulus of elasticity of conventional concrete.

5. Conclusions

From the results of study, the followings conclusions can be drawn:

- The compressive strengths of both conventional concrete and SCC decrease with the increase of the amount of styrofoam ALWA replacement. The higher the percentage of styrofoam ALWA replacement, the lower the compressive strength. The replacement to the natural coarse aggregate in both conventional concrete and SCC resulted the highest compressive strengths at about 15% with the compressive strengths of conventional concrete and SCC of about 21.13 and 28.33 MPa, respectively.
- The more styrofoam ALWA replacement, the smaller the modulus of elasticity of concrete. The modulus of elasticity of SCC is greater than that of the conventional concrete.
- The higher amount of ALWA used in self- compacting concrete (SCC), the lower workability level can be reached.

6. References

[1] Pudjisuryadi, P., Tavio, and Suprobo P. "Axial Compressive Behavior of Square Concrete Columns Externally Collared by Light Structural Steel Angle Sections." International Journal of Applied Engineering Research 11, no. 7 (2016): 4655–4666.

[2] Tavio, Kusuma B., and Suprobo, P. "Experimental Behavior of Concrete Columns Confined by Welded Wire Fabric as Transverse Reinforcement under Axial Compression." ACI Structural Journal 109, no. 3 (May–June 2012): 339–348. doi:10.14359/51683747.

[3] Tavio. "Interactive Mechanical Model for Shear Strength of Deep Beams." Journal of Structural Engineering 132, no. 5 (May 2006): 826 –827. doi:10.1061/(ASCE)0733-9445(2006)132:5(826)

[4] Kusuma, B., Tavio, and Suprobo P. "Axial Load Behavior of Concrete Columns with Welded Wire Fabric as Transverse Reinforcement." Procedia Engineering Elsevier 14 (2011): 2039–2047. doi:10.1016/j.proeng.2011.07.256.

[5] Astawa, M. D., Raka I G. P., and Tavio. "Moment Contribution Capacity of Tendon Prestressed Partial on Concrete Beam-Column Joint Interior According to Provisions ACI 318-2008 Chapter 21.5.2.5(c) Due to Cyclic Lateral Loads." MATEC Web of Conferences 58, no. 04005 (2016): 1–8. doi:10.1051/matecconf/20165804005

[6] Raka, I G. P., Tavio, and Astawa M. D. "State-of-the-Art Report on Partially-Prestressed Concrete Earthquake-Resistant Building Structures for Highly-Seismic Region." Procedia Engineering Elsevier 95 (2014): 43–53. doi:10.1016/j.proeng.2014.12.164.

[7] Basa, B. and Sethi J., "Fresh And Hardened Properties of Self Compacting Concrete using Fly Ash Lightweight Aggregate as Partial Replacement of Natural Coarse Aggregate," International Journal of Civil Engineering and Technology (August 2016): 7(4), 498–505.

[8] Maghsoudi, A. A., Mohamadpour S., and Maghsoudi M. "Mix Design and Mechanical Properties of Self Compacting Lightweight Concrete." International Journal of Civil Engineering 9, no. 3 (September 2011): 230–236.

[9] Ahmad, H. H. and Tavio. "Experimental Study of Cold-Bonded Artificial Lightweight Aggregate Concrete." AIP Conference Proceedings 1977 (2018): 030011-1–030011-8. doi:10.1063/1.5042931.

[10] Raharjo, D., Subakti A., and Tavio. "Mixed Concrete Optimization Using Fly Ash, Silica Fume and Iron Slag on the SCC's Compressive Strength." Procedia Engineering Elsevier 54 (2013): 827–839. doi:10.1016/j.proeng.2013.03.076.

[11] ACI Committee 318. "Building Code Requirements for Structural Concrete (ACI 318M-14) and Commentary (ACI 318RM-14)." American Concrete Institute (2014): 519.

[12] Pudjisuryadi, P., Tavio, and Suprobo P. "Performance of Square Reinforced Concrete Columns Externally Confined by Steel Angle Collars under Combined Axial and Lateral Load." Procedia Engineering Elsevier 125 (2015): 1043–1049. doi:10.1016/j.proeng.2015.11.160.

[13] Tavio, Suprobo P., and Kusuma B. "Ductility of Confined Reinforced Concrete Columns with Welded Reinforcement Grids." Excellence in Concrete Construction through Innovation–Proceedings of the International Conference on Concrete Construction (2009): 339–344. doi:10.1201/9780203883440.ch51

[14] Tavio, Kusuma B., and Suprobo P. "Investigation of Stress-Strain Models for Confinement of Concrete by Welded Wire Fabric." Procedia Engineering Elsevier 14 (2011): 2031–2038. doi:10.1016/j.proeng.2011.07.255.

[15] Astawa, M. D., Tavio, and Raka I G. P. "Ductile Structure Framework of Earthquake Resistant of High-Rise Building on Exterior Beam-Column Joint with the Partial Prestressed Concrete Beam-Column Reinforced Concrete." Procedia Engineering Elsevier 54 (2013): 413–427. doi:10.1016/j.proeng.2013.03.037

[16] Tavio and Teng S. "Effective Torsional Rigidity of Reinforced Concrete Members." ACI Structural Journal 101, no. 2 (2004): 252–260. doi:10.14359/13023.

[17] Anggraini, R., Tavio, Raka I G. P., and Agustiar. "Stress-Strain Relationship of High-Strength Steel (HSS) Reinforcing Bars." AIP Conference Proceedings 1964 (2018): 020025-1–020025-8. doi:10.1063/1.5038307.

[18] Tavio, Anggraini R., Raka I G. P., and Agustiar. "Tensile Strength/Yield Strength (TS/YS) Ratios of High-Strength Steel (HSS) Reinforcing Bars." AIP Conference Proceedings 1964 (2018): 020036-1–020036-8. doi:10.1063/1.5038318.

[19] Tavio and Parmo. "A Proposed Clamp System for Mechanical Connection of Reinforcing Steel Bars." International Journal of Applied Engineering Research 11, no. 11 (November 2016): 7355–7361. doi:10.31227/osf.io/96ngt.

[20] Vivek K., Bhavana B., Kumar P., and Kumar P. "Experimental Investigation on Properties of Self-Compacting and Self-Curing Concrete with Silica Fume and Light Weight Aggregates." International Journal of Engineering Research and Technology 4, no. 6 (June 2015): 203-210. doi:10.17577/ijertv4is060344.

[21] Ranjbar, M. M. and Mousavi S. Y. "Strength and Durability Assessment of Self-compacted Lightweight Concrete Containing Expanded Polystyrene." Materials and Structures 48, no. 4 (November 2013): 1001-1011. doi:10.1617/s11527-013-0210-6.

[22] Danish, P. and Islam S. "Effect of Styrofoam Balls and Aluminium Oxide on Strength Properties of Cement Motor Cubes." International Journal of Scientific and Engineering Research 6, no. 2 (Februari 2015): 1099-1102.

[23] Vakhshouri, B. and Nejadi S. "Mix Design of Light-Weight Self-Compacting Concrete." Case Studies in Construction Materials 4 (Juni 2016): 1-14. doi:10.1016/j.cscm.2015.10.002.

[24] Reddy, S. R., Reddy R., and Desai V. B. "An Experimental Study on Strength Properties of Styrofoam Light Weight Aggregate Concrete Modified With Penta Blended Cement (Pozzolanic Materials & Nano Al2O3)." International Journal of Engineering Science

and Computing 7, no. 2 (April 2017): 10233-10239.

[25] Modaraei, A. H., Rahmatmadandoust, and Nesaz B. B. “Properties of Fresh Lightweight Self-Compacting Concrete Containing Eps Beads.” Indian Journal of Fundamental and Applied Life Sciences 5 (2015): 2706-2713.

[26] ASTM Subcommittee C09.61. “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM C39/C39M-18).” ASTM International (2018). doi:10.1520/C0039_C0039M-18.

[27] EPG. “The European Guidelines for Self-Compacting Concrete: Specification, Production and Use.” European Project Group (May 2005): 63.

[28] ASTM Subcommittee C09.20. “Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates (ASTM C136/C136M-14).” ASTM International (2014). doi: 10.1520/C0136_C0136M-14.

[29] ASTM Subcommittee C09.21. “Standard Specification for Lightweight Aggregates for Structural Concrete (ASTM C330/C330M-17).” ASTM International (2017). doi: 10.1520/C0330_C0330M-17.

[30] Tavio and Kusuma B., “Stress-Strain Model for High-Strength Concrete Confined by Welded Wire Fabric.” Journal of Materials in Civil Engineering 21, no. 1 (January 2009): 40–45. doi:10.1061/(asce)0899-1561(2009)21:1(40).

[31] Tavio, Suprobo P., and Kusuma B. “Strength and Ductility Enhancement of Reinforced HSC Columns Confined with High-Strength Transverse Steel.” Proceedings of the Eleventh East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-11) (November 2008): 350-351.

[32] Agustiar; Tavio; Raka, I G. P.; and Anggraini, R., “Behavior of Concrete Columns Reinforced and Confined by High-Strength Steel Bars,” International Journal of Civil Engineering and Technology (July 2018): 9(7), 1249–1257.

[33] Sabariman, B., Soehardjono A., Wisnumurti, Wibowo A., and Tavio. “Stress-Strain Behavior of Steel Fiber-Reinforced Concrete Cylinders Spirally Confined with Steel Bars.” Advances in Civil Engineering 2018 (Juni 2018): 1–8. doi:10.1155/2018/6940532.