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Long-Term Behavior of Self-Compacting Concrete Incorporating Palm Oil Fuel Ash and Eggshell Powder as Partial Cement Replacement

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Abstract: Self-compacting concrete (SCC), is an innovative concrete that uses less aggregates, but high content of cement compared to normal concrete. It is able to flow by itself and does not require compaction. Therefore, the consumption of cement is higher in producing a good quality and strength of SCC. To minimize the usage of the cement in the SCC, Palm Oil Fuel Ash (POFA) and Eggshell Powder (ESP) were used as partial cement replacement materials for an alternative solution. This experimental work was conducted to study the mechanical behaviour of SCC incorporating POFA and ESP as cement replacement. The cement was partially replaced with 5% of POFA and 2.5% of ESP. A total of 18 cubes and 6 cylinders were prepared for determining compressive and tensile strength of SCC respectively, while 6 cylinders were additionally prepared to determine modulus of elasticity. The specimen of cubes were cast in dimensions 100 mm x 100 mm x 100 mm for compressive test at ages 7, 28 and 56 days. Meanwhile, cylinders were cast in diameter 100 mm with height 200 mm for tensile test and modulus of elasticity, at the age of 28 days. The workability of the fresh concrete also was determined by using tests such as slump flow, J-ring and segregation tests. It has been verified that SCC with addition of POFA and ESP had better workability compare to conventional SCC. Furthermore, based on the results, it was observed that the combination POFA and ESP as cement replacement in SCC had good effect on the compressive and tensile strength. It was found that 5% POFA and 2.5% ESP in SCC had maximum compressive and tensile strength of 4.01% and 6.85% higher than conventional SCC achieved. The results, it shows the mixture of 5% POFA and 2.5% ESP in SCC had greater performance and more environmentally friendly than conventional SCC.

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Keywords: Self-compacting Concrete (SCC), POFA, Eggshell Powder (ESP)

1. Introduction

Self-consolidating concrete also known as self-compacting concrete, has become an innovation in technology that can easily flow into place under its weight and fill congestion areas of reinforcement structures without the need to vibrate and without segregation of its constituents. Normal concrete usually placed and vibrated in the formwork but SCC does not vibrate, it should flow easily and compact by gravity [1]. Such concrete must have a relatively low yield strength to provide high flow and must maintain its uniformity during shipping, placement, and curing to ensure adequate structural performance and long-term strength. Successful SCC development must provide a good balance between deformability and stability.

POFA and ESP is agriculture and food waste that generated in abundance in Malaysia. POFA is produced in the palm oil industry by burning empty fruit bunches (EFB), fiber and oil palm shell (OPS) as fuel to generate electricity at temperatures around 800-1000°C and the waste as ash becomes POFA [2]. POFA is mostly dumped into the open fields without treatment which causing environmental pollution. Meanwhile, ESP is a bio-waste from a restaurant that disposed to landfills, causing scarcity of land. POFA for chemical properties has a high content of silica oxide (SiO2) but limited content of calcium oxide [3] while ESP has a high content of calcium oxide (CaO) and limited content of silica oxide [4] which make it a good combination to use together. The processing of POFA and ESP into a useful product offers good potential for the agricultural industry, food industry and the construction industry. This is because the use of waste can reduce the cost of cement and production, but it will also reduce the cost of landfill activities at the same time reduce the pollution. The use of by-products such as POFA and ESP as partial cement replacement can help reduce the demand for Portland cement by partially replacing the cement contains, producing strong concrete and minimizing emissions of greenhouse gases. This can make cement and concrete production more environmentally friendly while reducing solid waste and improving air quality.

To further advance the use of SCC in civil engineering, systematic studies of the long-term behaviour of SCC has been carried out. Long-term behaviour can be analysed from compressive and tensile strength. Compressive strength is the most important mechanical property of any concrete including SCC. The main factor affecting compressive strength is the type of cement, water-cement ratio, aggregate, tests parameters, sample parameters, loading conditions, age and degree of proof hydration. It is mainly affected by time and curing methods. Tensile strength also is one of the important properties of concrete because concrete structures are very vulnerable to tensile cracking due to various kinds of effects. Moreover, the concrete is very weak in tension due to its brittle nature.

2. Literature Review

SCC contain high fluidity, which can be placed under its own weight without the use of a mechanical vibrator for placing and compaction. It was first produced in Japan in 1986 as a new type of high-performance concrete (HPC) with superior resistance to deformation. SCC has been introduced by Professor Okamura and later developed by Ozawa and Maekawa and their team at the University of Tokyo in Japan to improve construction quality and address inadequate workmanship issues [5]. SCC often used now because it can shorten the construction period in large-scale construction and can eliminate vibration noise. It possesses superior flow ability with is under-maintained stability [6].

POFA is produced in the palm oil industry by burning empty fruit bunches (EFB), fiber and oil palm shell (OPS) as fuel to generate electricity at temperatures around 800-1000°C and the waste as ash becomes POFA [2]. POFA has high potential to be used as a good cement replacement material [7]. According to [8], SCC with 10% POFA had a higher compressive strength than control samples (0% POFA) in a 28-day curing process. In addition, [7] used POFA as a cement replacement in SCC mixtures with a change in the water-cement ratio and the percentage of POFA. The higher compressive strength development is associated with a lower water-cement ratio in the SCC mix at any age of curing.

ESP is a bio-waste from a restaurant that disposed to landfills, causing scarcity of land. It can be used to reduce building expenses at the same time reduce environmental pollution by recycling them. The main composition of the eggshell is calcium oxide with is stand up to 50.7% of eggshell chemical composition [9]. By using eggshell waste instead of natural lime as a replacement cement in concrete can bring benefits such as reducing cement consumption, utilized waste and conserving natural lime [4]. According to [10], It can be observed that the optimal compressive strength at 28 days is 5% of the ESP as a replacement for cement in concrete. The compressive strength decrease when the percentage of ESP increases [11].

One of the most important features used in the design rules of concrete structures is the compressive strength of concrete. Compared to the vibrated concrete, the compressive strength of SCC is higher at the same water-cement ratio [12]. Splitting tensile strength also was performed to determine the tensile strength of the concrete. However, due to its low tensile strength and brittle nature, concrete is unexpectedly resisted tension. According to [13] investigated the effect of combined POFA and ESP as a replacement for cement in SCC with variable percentages of POFA and ESP from 0% to 15%. The compressive and splitting tensile strength of SCC were reduced by excessive content of POFA and ESP. It can be seen that SCC with the addition of 5% POFA and 2.5% ESP was the most effective and suitable for structural purposes after achieving a compressive and tensile strength of 38.60 MPa and 3.24 MPa after 28 days of curing.

3. Materials and Methods

3.1 Materials

The material that used in producing SCC is POFA and ESP as cement replacement, which is consist of cement, sand, aggregate, water, POFA and ESP. The type of cement used was Tasek Cement. Raw POFA was collected from Ban Dung Palm Oil Factory in Parit Sulong, Batu Pahat, Johor. It was oven-dried at 110 °C for 24 hours and grinded for about 3 hours in the grinder machine. POFA was sieved with a size of 75µm to increase the fineness. ESP was collected at Rengit, Batu Pahat, Johor. Eggshell was put in the oven at temperature 110 °C for 24 hours. Dry eggshell was ground into powder form and it was sieved through 75µm.

3.2 Mix Proportion

The cement was replaced with 5% POFA and 2.5% ESP. It was designed according to [14] European guidelines for SCC. The mixing proportions of all ingredients were presented in Table 1.

Table 1: Mixing proportion of SCC ingredients

Mix Proportion	Cement (kg/m^3)	POFA (kg/m^3)	ESP (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Water (kg/m^3)	Superplasticizer (kg/m^3)
Control	451	0	0	902	767	180	9.02
SCC 5P 2.5E	417.17	22.55	11.28	902	767	180	9.02

3.3 Specimens Preparation

In this study, eighteen cube specimens were cast in dimensions 100 mm x 100 mm x 100 mm for compressive tests at the ages 7, 28 and 56 days. Meanwhile, in a total of twelve cylinder specimens were cast in diameter 100 mm with height 200 mm, six for tensile test and six for modulus of elasticity test, at the age 28 days.

3.4 Testing

The specimens were investigated for compressive strength, splitting tensile strength and modulus of elasticity. The compressive strength test was in accordance with BS EN 12390-3:2009 standard while the splitting tensile test was in accordance to BS EN 12390-6:2009 standard. The modulus of elasticity test also involves a series of test on cylinder specimens according to the standard BS 12390-13:2013 and ASTM C469. For the fresh properties of POFA and ESP, it consists of three types of test, which is J-ring, segregation test and slump flow test. The J-ring test was in accordance to BS EN 12350-12:2010 standard while segregation test was accordance to BS EN 12350-11:2010 standard. The procedure of slump flow test was referred from BS EN 12350-8:2017.

4. Results and Discussion

4.1 Slump Flow

The slump flow test was used to indicates the filling ability of concrete. The acceptable range of slump flow which is from 550 mm to 850 mm is needed for SCC. Figure 1 shows the highest average diameter recorded was the control mixture which 575 mm. The lowest average diameter recorded from specimen 5% POFA 2.5% ESP was 560 mm.

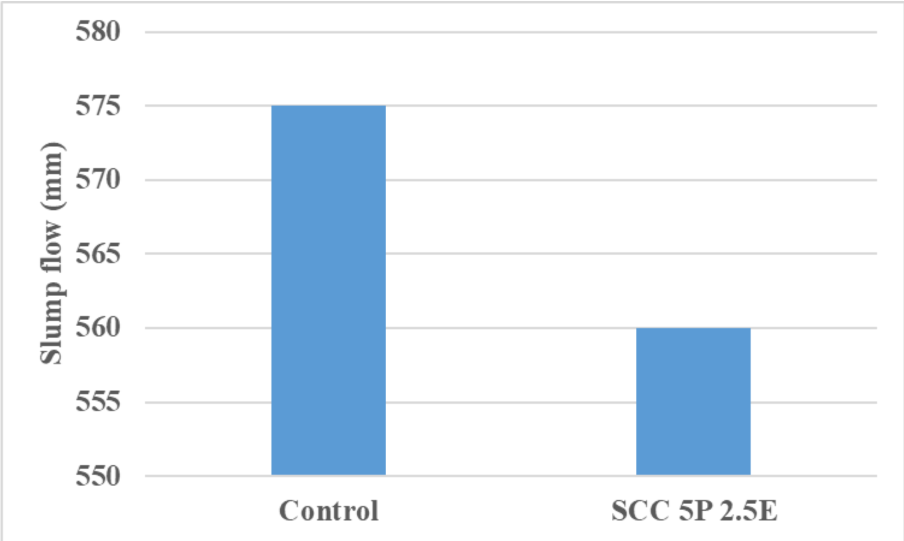

Figure 1: Slump flow of SCC

The data recorded on the slump flow test shows that, slump flow of SCC significantly decreased due to added percentages of POFA and ESP. The difference in diameter for control and SCC was 15 mm which is 2.61 percent. When POFA and ESP were added in SCC, the demand for water content increases due to low specific gravity of both POFA and ESP. Slump-flow of SCC decreased due to added percentage of POFA [8]. The overall conclusion shows that all mix proportion was under a range of SCC standard diameter.

4.2 J-Ring Test

The J-ring test was used to determine the passing ability of SCC. SCC could pass under its weight without vibration to flow and fill the spaces. Figure 2 shows the J-ring flow.

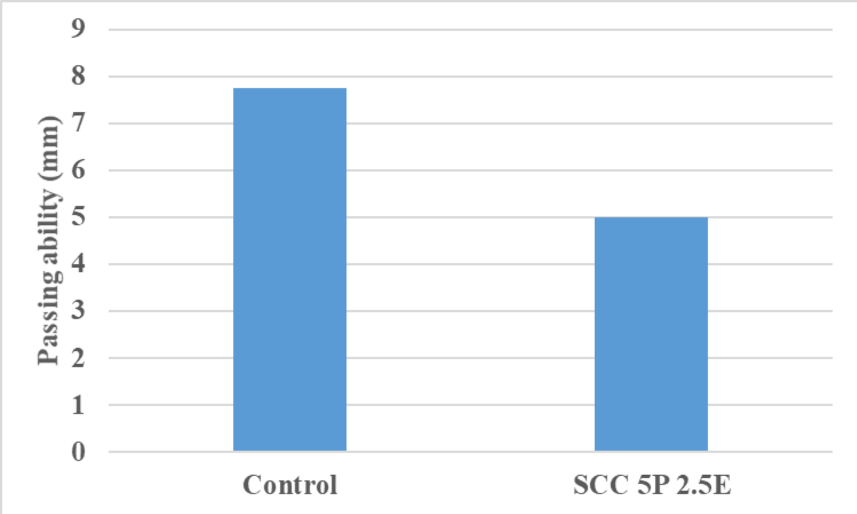

Figure 2: Passing ability of SCC

From the result of J-ring flow, SCC specimen with POFA and ESP as cement replacement have the lowest passing ability. Meanwhile, the control specimen gave a high passing ability. It shows that the materials have high absorbance towards liquidity in the concrete mix. The requirement from EFNARC (2005) states that the passing ability of J-ring flow must less than 10mm. Results for J-ring flow of all specimens fulfilled the requirement.

4.3 Segregation Test

Segregation test was used to investigate the resistance of SCC to segregation using a 5mm sieve and check whether any fresh sample of SCC passed through the sieve. Figure 3 below shows result for segregation sieve.

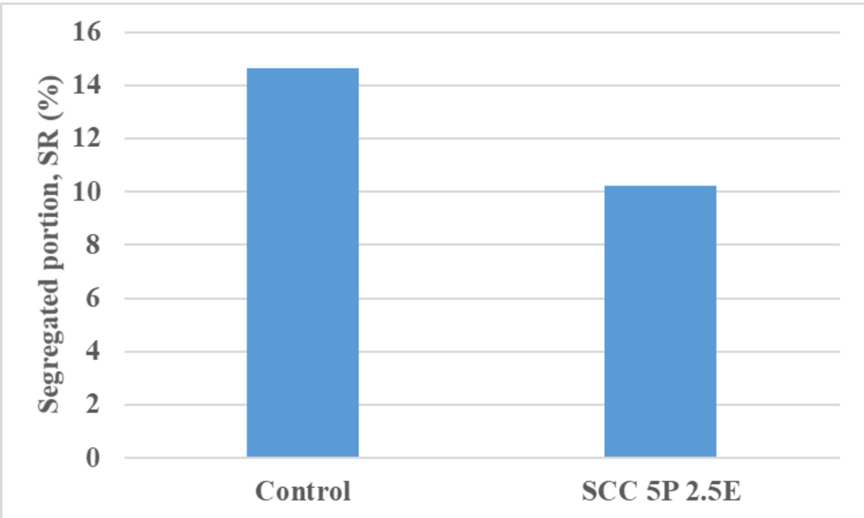

Figure 3: Result for segregration sieve

The segregated below 20% was the requirement needed to be obtained by the sample according to EFNARC 2005 specifications for sieve segregation test. From the result, it shows that specimens with 5% POFA and 2.5% ESP have the lowest percentage of segregation. The difference in percentage for control and SCC was 4.41 percent which is 30.10 percent indifferent. It because the incorporation of POFA and ESP enhanced the adhesion properties in the SCC. The highest value of segregation was recorded by the control specimen.

4.4 Compression Test

The results for compressive strength were shown in Table 2. The compressive strength of the control sample was 19.8 MPa, 41.8 MPa and 42.4 MPa at 7, 28 and 56 days respectively. From Table 2, it can be observed that the addition of POFA along with ESP as cement replacement was beneficial in increasing compressive strength.

Table 2: Compressive strength of SCC for 7, 28 and 56 days

Mix proportion	No. of sample	Compressive strength (MPa)			Average compressive strength (MPa)			Percentage of compressive strength with control (%)		
		7 days	28 days	56 days	7 days	28 days	56 days	7 days	28 days	56 days
Control	1	19.8	41.8	43.0	19.8	41.8	42.4	0	0	0
	2	20.2	42.5	42.4						
	3	19.3	41.0	41.9						
SCC 5P 2.5E	1	20.7	44.7	45.2	21.4	43.3	44.1	±8.08	±3.59	±4.01
	2	22.0	43.3	43.0						
	3	21.4	41.9	44.1						

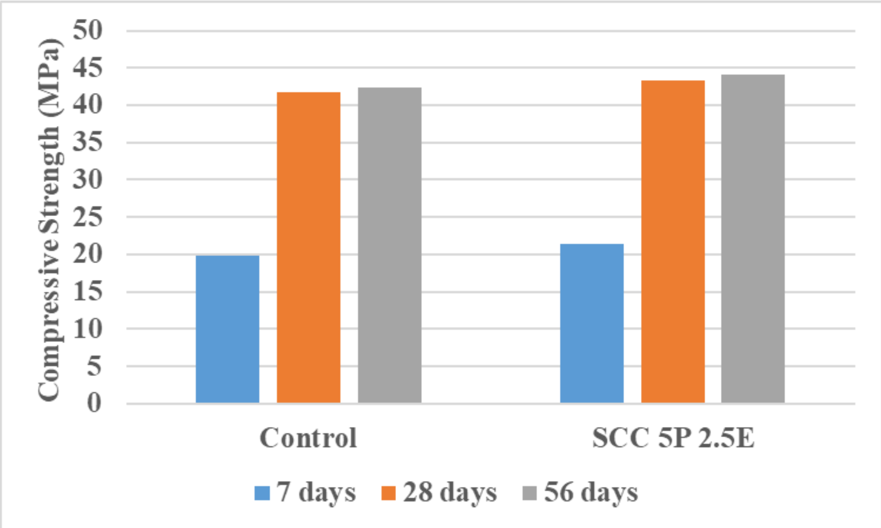

Figure 4: Compressive strength of SCC

From Figure 4, the compressive strength was recorded that the lowest point was controlled specimen on 7 days, which 19.8 MPa. The highest compressive strength was specimen with 5% POFA and 2.5% ESP on 56 day, which 44.1 MPa. The difference between the highest and the lowest in this compressive strength is 24.3 MPa. For compressive strength at 7 days, the specimen of 5% POFA 2.5% ESP was recorded that the percentage reduction of strength were about 8.08 percent from the control sample of SCC. For the 28 and 56 days, the values difference between control specimen was 3.59 and 4.01 percent. Highly reactive silica in POFA was the main reason behind the increase in compressive strength. The average strength at 56 days of curing for SCC samples was higher than those of 7 and 28 days of curing.

Meanwhile, the percentage of compressive strength between 28 and 56 days also was showed in Table 3. For the control sample, the percentage of compressive strength was 1.44 percent between 28 and 56 days while the specimen of 5% POFA and 2.5% ESP was recorded the percentage were about 1.85 percent. It can be observed that the compressive strength was increase with the increase in time.

Table 3: Percentage of compressive strength between 28 and 56 days

Mix proportion	Average compressive strength (MPa)		Percentage compressive strength between 28 and 56 days
	28 days	56 days	
Control	41.8	42.4	±1.44
SCC 5P 2.5E	43.3	44.1	±1.85

4.5 Splitting Tensile Strength

Table 4 shows the result obtained from SCC and the tensile strengths are recorded. It was observed that the tensile strength of SCC control sample is 1.48 MPa when tested after 28 days of water curing. Splitting tensile strength was increased to 1.63 MPa which is 6.85% increment for specimen of SCC with 5% POFA 2.5% ESP and become higher than control specimen. Figure 5, it shows that the behaviour of tensile strength of SCC was similar to its compressive strength. The pozzolanic creates additional C-S-H gels which increase both compressive and tensile strength.

Table 4: Splitting tensile strength of SCC

Mix proportion	No. of sample	Tensile strength (MPa)	Average tensile strength (MPa)	Difference in Strength compared to control (%)
Control	1	1.91	1.48	0
	2	1.48		
	3	1.06		
SCC 5P 2.5E	1	1.25	1.63	6.85
	2	1.93		
	3	1.72		

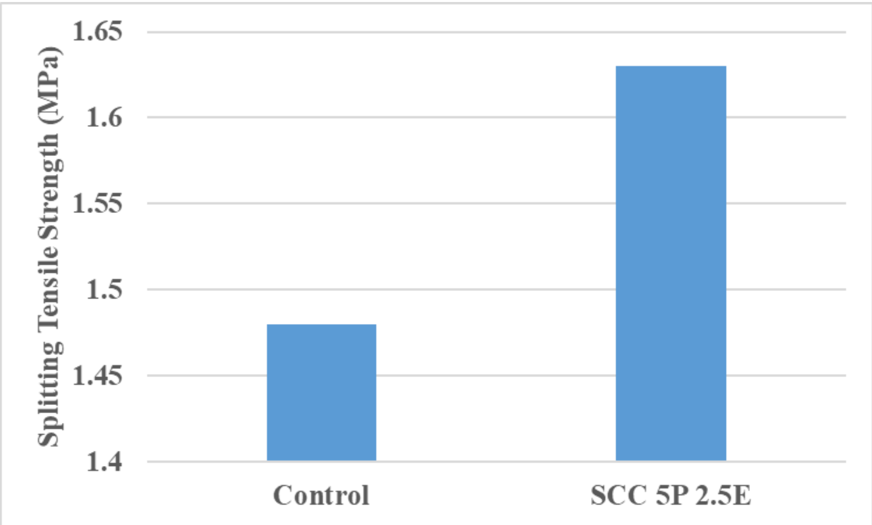

Figure 5: Tensile strength of SCC

4.6 Modulus of Elasticity (MOE)

The determination of MOE can be achieved by using the stress-strain graph. The cylinder samples used dial gauge to measure the strain. Table 5 shows the elastic modulus SCC for 28 days.

Table 5: Modulus of elasticity, (MOE) of SCC 28 days

Mixes	MOE values, E (N/mm²)			
	MOE (MPa)	Control MOE (MPa)	MOE increased	MOE increased (%)
Control	18159	18159	0	0
SCC 5P 2.5E	21296	18159	3137	17.28

From Table 5 above, it shows the MOE values of the control sample was recorded to be 18159 N/mm² while the 5% POFA and 2.5% ESP sample recorded 21296 N/mm². The difference in these MOE value was 3137 MPa which is 17.28 percent in difference. Based on the result shown, it can be observed that the MOE of SCC increased when percentage of cement was replaced by 5% POFA and 2.5% ESP. It can be said that the enhancement in pozzolanic reaction with the addition of ESP increased the MOE.

5. Conclusion

Based on the laboratory result, conclusion can be made from an experimental study conducted on POFA and ESP as a cement replacement for concrete. For workability of SCC, it was tested with slump flow test, J-ring test and segregation test. From the result obtained for all experimental testing, the addition of POFA and ESP as cement replacement in SCC resulted in a decrease of filling ability and passing ability were about 2.61% and 35.5%, which passed the requirement for height of the spread and the segregation resistance was improved about 30.1% indifferent. It has been verified that SCC with the addition of POFA and ESP had better workability compare to conventional SCC. For mechanical behavior, the results was concluded that compressive strength, tensile strength and MOE significantly increased when POFA and ESP were used as partial cement replacement. The maximum compressive strength, tensile strength and MOE achieved were 44.1 MPa, 1.63 MPa and 21296 MPa respectively by 5P 2.5E mix, which was approximately 4.01%, 6.85% and 17.28% higher compared to the control sample. By achieving a compressive strength of 44.1 MPa at the curing age of 56-days, 5P 2.5E mix was considered suitable for structural purposes. The percentage of compressive strength increased between 28 and 56 days for 5P 2.5E SCC was about 1.85% compared to conventional SCC, which is 1.44%. It shows that the increase in time can also increase the compressive strength for the long term behaviour.

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References

[1] Aslani, F., Ma, G., Wan, D. L. Y., & Muselin, G. (2018). Development of high-performance self-compacting concrete using waste recycled concrete aggregates and rubber granules. *J. Cleaner Prod.*, 182, 553-566.

[2] Nagaratnam, B. H., Rahman, M. E., Mirasa, A. K., Mannan, M. A., & Lame, S. O. (2015). Workability and heat of hydration of self-compacting concrete incorporating agro industrial waste. *J. Clean. Prod.*

[3] Narendra, A. R., & Pathrose C. G. (2017). Development of thermally efficient fibre-based eco-friendly brick reusing locally available waste materials. *Department of Construction Management*, *Universiti Tun Hussein Onn Malaysia*, 133, 275-284.

[4] Yerramala, A. (2014). Properties of concrete with eggshell powder as cement replacement. *Indian Concrete Journal*, *88*(10), 94–102.

[5] Maekawa, K., & Ozawa, K. (1999). Development of SCC's prototype, self-compacting high-performance concrete. *Soc. Syst. Inst.*, 20-32.

[6] Mahesh, S. (2014). Self-Compacting Concrete and Its Properties. *Department of Civil Engineering, Dadi Institute of Engineering and Technology*, 72-80.

[7] Mohammadhosseini, H., Abdul Awal, A. S. M., & Ehsan, A. H. (2015). Influence of palm oil fuel ash on fresh and mechanical properties of self-compacting concrete. *Sadhana*, 40(6).

[8] Alsubari, B., Shafigh, P., Jumaat, M. Z., & Alengaram, U. J. (2014). Palm oil fuel ash as a partial cement replacement for producing durable self-consolidating high-strength concrete. *Department of Civil Engineering, Faculty of Engineering, University of Malaya*, 39(12), 8507-8516.

[9] Freire, M. N., & Holanda, J. (2006). Characterization of avian eggshell waste aiming its use in a ceramic wall tile paste. *LAMAV-GMCer*, *Universidade Estadual do Norte Fluminense*, 52, 240-244.

[10] Al-Safy, R. (2015). Experimental investigation on properties of cement mortar incorporating eggshell powder. *Al-Mustansiriya University*.

[11] Mohamed Ansari, M., Dinesh Kumar, M., Milan Charles, J., & Vani, G. (2016). Replacement of cement using eggshell powder. *International Journal of Civil Engineering*, 3(3), 1-2.

[12] Bradu, A., Cazacu, N., Florea, N., & Mihai, P. (2016). Modulus of elasticity of self-compacting concrete with differents levels of limestone powder. *"Gheorghe Asachi" Technical University of Iasi*, 62, 66.

[13] Kamaruddin, S., Goh, W. I., Abdul Mutalib, N. A. N., Jhatial, A. A., Mohamad, N., & Rahman, A. F. (2021). Effect of Combined Supplementary Cementitious Materials on the Fresh and Mechanical Properties of Eco-Efficient Self-Compacting Concrete. *Faculty of Civil Engineering and Built Environment, Jamilus Research Centre, University Tun Hussein Onn Malaysia.*

[14] EFNARC. (2005). The European Guidelines for Self-Compacting Concrete. *The European Guidelines for Self-Compacting Concrete*, 63. Retrieved from http://www.efnarc.org/pdf/SCCGuidelinesMay2005.pdf