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Flexural Study of Reinforced Foamed Concrete Beam Containing Palm Oil Fuel Ash (POFA) and Eggshell Powder (ESP) as Partial Cement Replacement

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Abstract: The fabrication process of concrete in the construction has caused carbon dioxide released into the atmosphere subsequently increases carbon footprint. Meanwhile, large sum of agricultural waste are generated such as palm oil fuel ash (POFA) and eggshell powder (ESP). Incorporation of supplementary cementitious materials by capitalizing agricultural waste into concrete regarded as sustainable effort to reduce environmental impact. In this study, foamed concrete (FC-POFA-ES) was incorporated with 20% of POFA, 5% and 10% of ESP. Beam specimens 20 POFA 10 ESP has +14% and 20 POFA 05 ESP +13% higher ultimate load capacity but more severe cracking compared to control mix. The mix proportion of 20 POFA 10 ESP has better overall strength compared with control beam from experimental works. Therefore, it can be concluded the addition of POFA and ES powder has potential to be explored as cement replacement in foamed concrete structure

Keywords: Foamed concrete, Palm Oil Fuel Ash, Eggshell Powder, cement replacement

1. Introduction

Concrete is the primary material used in physical development of structure worldwide. Mass production of cement enable construction of structural building made from concrete with various feature suitable with the intended design purposes. Demand of concrete as construction material can be attributed due high durability, strength, mouldable and relatively economic compared with more traditional materials. Normal concrete typically used in construction has density of 2400 kg/m^3. Meanwhile, foamed concrete is known as a lightweight concrete with density ranging from 300 –1900 kg/m^3 by introducing air-voids (Zhang *et al.*, 2014) using foaming agent in the mortar.

Foamed concrete functioned as non-load bearing structure due to low density which reduces dead load rather than normal weight concrete (Ahmad *et al.*, 2008; Aichele & Felbermayr, 2012; Juenger & Siddique, 2015). Constituent materials mixes include basic component such as cement for binder while fine aggregates as filling materials of foamed concrete. However, carbon waste is simultaneously generated for the production of cement (Yerramala, 2014) thereby resulting environmental impact. Production of greener concrete can be achieved through waste minimization and reduction of raw materials which offering vast opportunities to be explored (Jhatial *et al.*, 2017). In conjunction with the binder materials from the foamed concrete, cement replacement is available as an option to reduce environmental impact. Supplementary cementitious materials (SCM) has been practiced since early

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age of technology to reduce natural Portland cement content with other pozzolan materials as a portion of replacement in concrete (Alex & Tiwari, 2015).

Malaysia palm oil is the biggest agricultural activity with 17.32 million tonnes of crude palm oil yield export revenue at RM 64.58 billion in 2017 according to Malaysia Palm Oil Berhad Annual Report. Palm oil byproduct may in form of fruit bunch, shell, fuel ash and effluent. Palm oil mills in Malaysia produces tonnes of POFA and disposed without fully utilized as secondary product either in agriculture fertilizer or engineering materials (Altwair *et al.*, 2012). POFA is classified into pozzolanic materials Class C and Class F according to ASTM C618 due high silica and aluminium oxide content which suitable for cement replacement materials.

On the other hand, Malaysian eggs consumption recorded 830.53 metric tonnes (Annual Agricultural Report, 2017) and expected to increases proportionally with trend of population. Demand from food industry secured local market for egg which also simultaneously produces eggshell waste. Direct impact from dumped egg shell waste exhibit foul odor, stockpile occupies land space and cause health problems due to vermin. Sustainable approach has become the critical challenges in construction industry due to depleting natural resources and increase in carbon footprint (Tan *et al.*, 2013) .

1.1 Previous Studies on POFA

Previous studies were investigated the effect of POFA as partial cement replacement materials ranging from 10% to 50%. (Munir *et al.*, 2015) discovered the compressive strength was reduced until 40% when the 50% POFA as cement replacement added into foamed concrete while other researcher (Tangchirapat & Jaturapitakkul, 2010) found strength of concrete reduced to 84% than control mix with cement replacement 30% POFA. However, other researcher (Momeen *et al.*, 2016; Muthusamy & Zamri, 2016) found use of POFA as partial cement replacement amount 10% to 15% improved the compressive strength of concrete.

Recent studies also shows interest toward the combination of POFA with eggshell waste. Eggshells have been investigated in the form of lime as calcium oxide (CaO) in cement replacement materials (Abdullah *et al.*, 2006; Thakrele, 2014). Combination of high silica oxide in POFA and calcium oxide in eggshell waste has potential as cement replacement materials. In term of fresh state property, workability of foamed concrete reduced without blocking with increment of POFA and ESA 30% as cement replacement, (Kamaruddin et al, 2018). Other researcher (Abd Khalid *et al.*, 2019) reported addition of 10% ground POFA and 10% eggshell with particle size 300 µm will improvise the compressive strength compared to normal concrete. Further studies on POFA with eggshell will be valuable to understand the effect in term of tensile strength, durability, thermal performance and elasticity. Nevertheless, studies related with structural behavior beam made of POFA with ESP as cement replacement is limited. Hence, this study conducted experimental work on reinforced foamed concrete beam containing POFA and ESP as partial cement replacement.

2. Material and Method

2.1 Materials Preparation

In the following section, the process starting from raw material of FC-POFA-ES will be explained. Moisture of POFA was eliminated by oven dry method at 105°C before a preliminary sieve with 300 mm. Then, the POFA in Figure 1(a) was grinded be-fore finally sieved at 150 µm to be used as partial cement replacement. Next, the egg shell waste shown as Figure 1(b) was cleaned with tap water to remove residual egg fluid. Cleaned egg shell was oven dried at the temperature 105°C subsequently grinded to process into powder. Egg shell powder was sieved at 150µm before used as partial cement replacement.

(a) (b)

Fig. 1- (a): Palm Oil Fuel Ash; (b) Egg Shell Waste

2.2 Experimental Programme

This study on foamed concrete were consist of laboratory work with experimental testing of beam specimens. The target density of the wet concrete have been set at 1800 kg/m^3. The previous studies selected the target fresh density of concrete used as the basis of design (Müllera *et al.*, 2014; Munir *et al.*, 2015; Ramamurthy *et al.*, 2009). In this study, the controlled water / cement ratio at 0.55 was selected. Meanwhile, fine aggregate content for the foamed concrete was twice proportion of cement. Summary of mix proportion tabulated as Table 1 was used in this study.

Table 1 - Design mix proportion of foamed concrete

Fresh Density (kg/m^3)	Proportion Ratio		
	Water	Cement	Fine Aggregate
1800	0.55	1.00	2.00

Two mixes containing 20% POFA + 5% ES powder and 20% POFA + 10% ES powder of cement replacement have been compared. Control mix with 0% POFA + 0% ES powder was cast as basis reference. Laboratory testing were conducted at 28th to flexural behavior of beam in term of cracking pattern, failure mode and load vs deflection.

2.3 Beam Designation and Experimental Setup

A total of 3 beams from each foam concrete mixes were fabricated. Beam dimension was fixed with length of 1500 mm while cross sectional area at 200 mm depth and 100 mm width. The design of moment carried out by stress block according to code of specification BS EN 1992-1-2:2004. The beams were de-signed as double reinforced of 2Y8 high tensile bar and R4 mild steel round bar of stirrups as illustrated in the Figure 2.

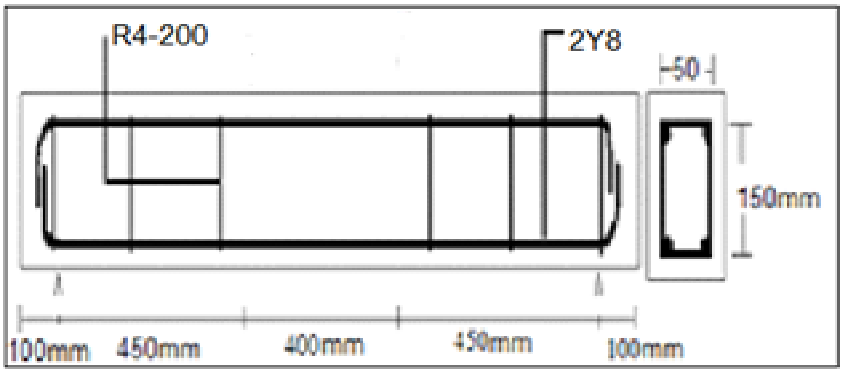


Fig. 2 - Design beam detailing

Beam specimen tested with four point load test to determine failure load according to BS EN 12390-5:2009 at 28th day with Magnus frame in Material and Structure Laboratory, UTHM. Four point load system utilizing two loads equally spaced from their adjacent support point with a distance between load points of one-third of the beam span. Figure 3 shows beam arrangement during testing.

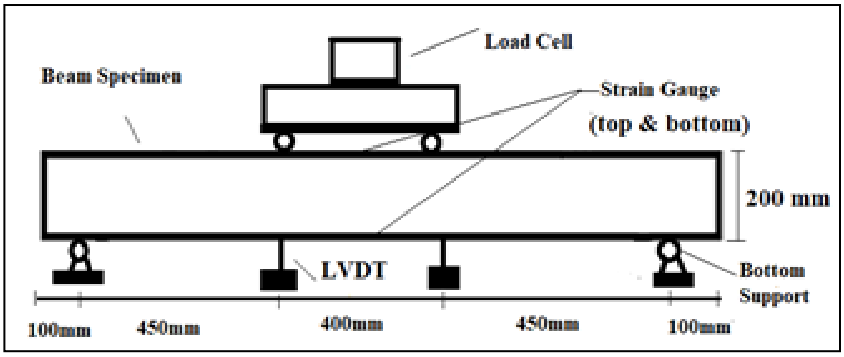


Fig. 3 - Experimental beam setup

3 Result and Discussion

3.1 Flexural Strength

Four point load test was conducted according to determine the flexural strength of beam specimens of FC-POFA-ES used in the study. Result from Table 2 shows the strength for Control mix, 20P5E and 20P10E respectively. Control mix has the lowest value at 7.8 MPa while both 20P5E and 20P10E recorded higher strength at 9.0 MPa and 9.2 MPa respectively. Improvement on flexural strength can be observed at 13% for mix 20P5E while 14% for mix 20P10E.

Table 2 - Flexural strength of control, 20P5E and 20P10E beam

Type of concrete mix	Age (days)	Average flexural strength (MPa)	Percentage different against control mix
Control	28	7.8	
20P5E	28	9.0	+13%
20P10E	28	9.2	+14%

The interaction of both POFA and ESP as binding materials was able to achieve the higher flexural strength. Variation of performance in the concrete also still contributed to POFA origin, fineness during processes and burning temperature in oil mill as stated by previous researcher (Lim *et al.*, 2013; Suhendro, 2014)Therefore, several factor combined were producing FC-POFA-ES to have more resistance against bending failure due higher flexural strength capacity compared with control foamed concrete.

3.2 Failure Mode and Cracking Pattern of Beam

Load was gradually applied on beam until the failure mode and ultimate load achieved. Table 3 and Figure 4(a-c) shows cracking loads and failure mode of beam. Generally, it can be observed that all beam have similar shear-flexure failure but FC-POFA-ES have higher number in term of cracking. The initial cracks at the middle with size of 50 mm for control beam recorded when the applied loading was 6.0 kN. Then several crack observed has propagated within flexure zone. When the ultimate load at 15.6 kN reached, the beam was experienced flexure-shear failure at overlay end.

Table 3 - Cracking load and failure mode of beam

Concrete Mix	Crack Load (kN)	1st Crack		Failure mode	
		Percentage of ultimate load (%)	Size (mm)	Failure type	Ultimate load (kN)
Control	6.0	38.5	50	Flexure-Shear	15.6
20P05E	7.2	40.0	93	Flexure	18.0
20P10E	7.2	38.8	80	Flexure-Shear	18.2

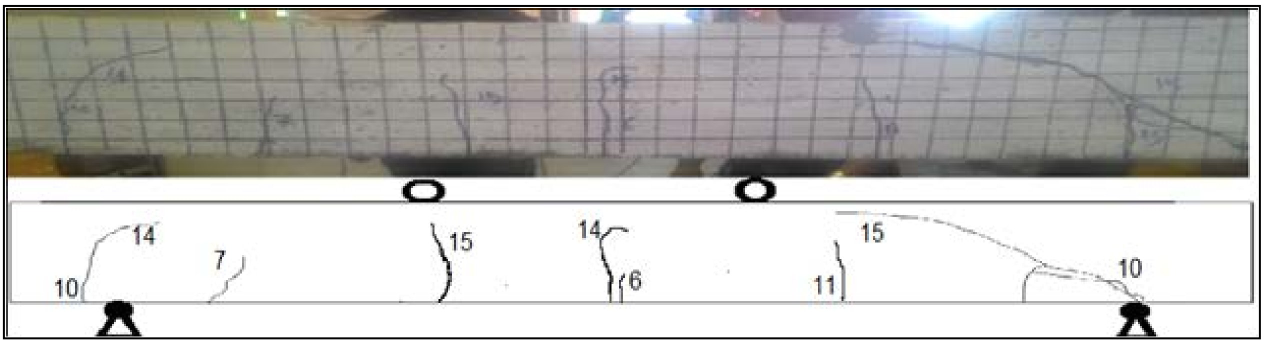


Fig. 4(a) - Cracking pattern of control beam specimen

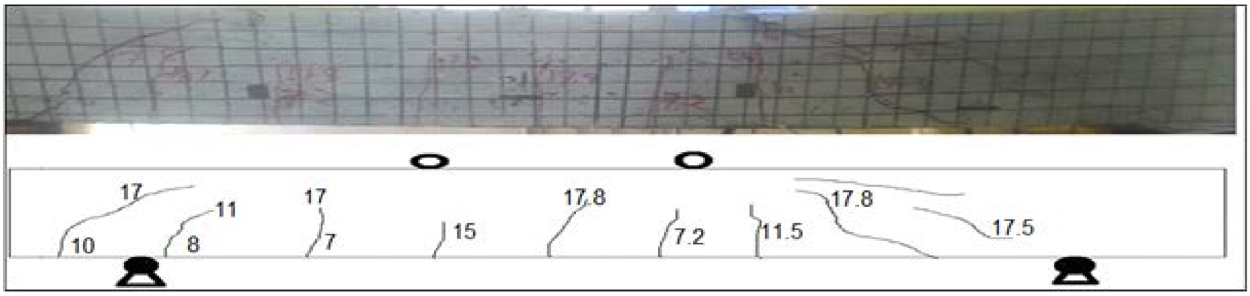


Fig. 4(b) - Cracking pattern of 20P5E beam specimen

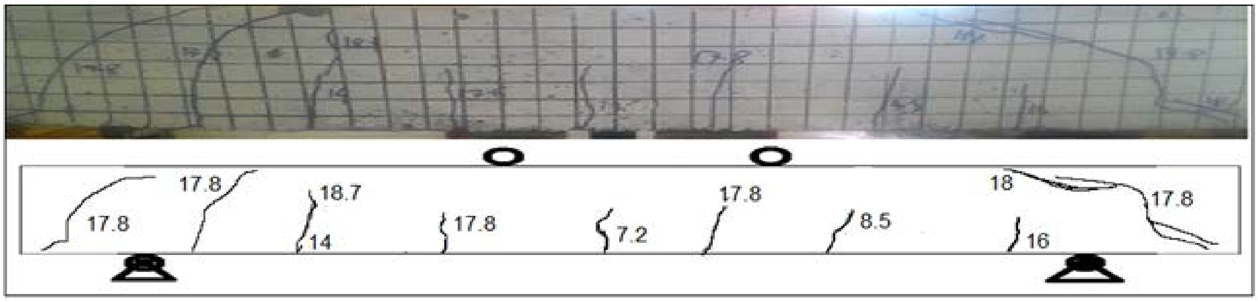


Fig. 4(c) - Cracking pattern of 20P10E beam specimen

Control and 20P10E beam have similar mode flexure failure unlike 20P5P with flexure failure near overlay end. The strong correlation between initial cracking and cement materials addition also determined by the previous study (Momeen et al, 2016).

3.3 Load vs Displacement

Figure 5 illustrate the comparison of beam deflection against axial load applied of the beam. The deflection occurred in both loading points of beam shared identical deflection profile which confirms the beam loadings was balanced. In general, it can be observed that when load exerted at 50% the ultimate load value, similar trend of displacement up to 2mm was recorded.

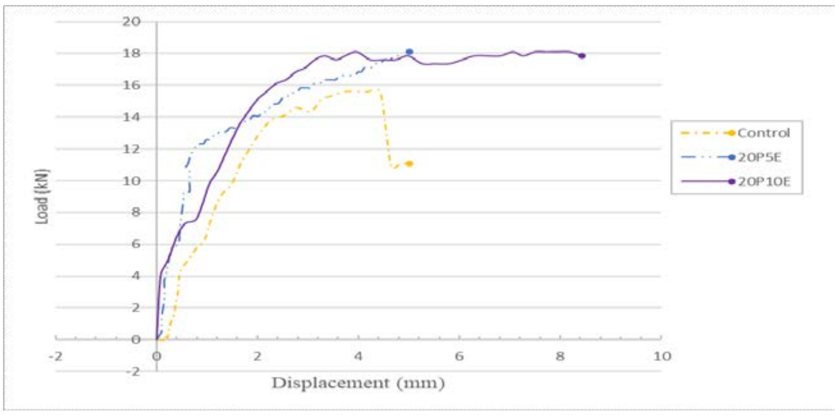


Fig. 5 - Ultimate load vs vertical displacement of FC-POFA-ES beam

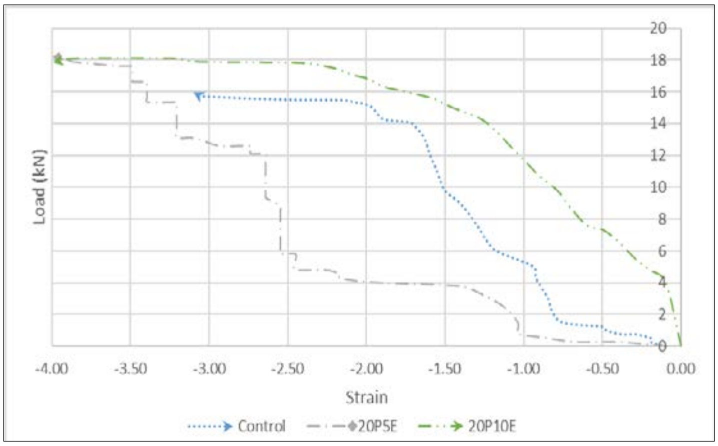
The mix 20P10E shows displacement stated when load exerted at 6 kN before increases gradually towards maximum value 7.25mm at 18.2kN. Mix 20P5E has maximum displacement recorded 5.81mm at 18.0kN while control beam has average 4.59mm deflection at 15.6kN. In comparison, both FC-POFA-ES mixes has lesser displacement value upon reaching 15.6kN at 2.13mm and 2.85mm respectively which indicates better deflection resistance capacity compared with control mix. The cement replacement from POFA and ES matrix improves the binding concrete particle thus reducing the displacement of beam (Lim *et al.*, 2013; Tangchirapat & Jaturapitakkul, 2010). Table 4 shows different displacement values of FC-POFA-ES. Mix type 20P5E can be observed has the highest bending resistance ratio at the ultimate load. In general, both mixes has higher displacement values compared with the control mix.

Table 4 - Vertical load vs average displacement of beam specimens

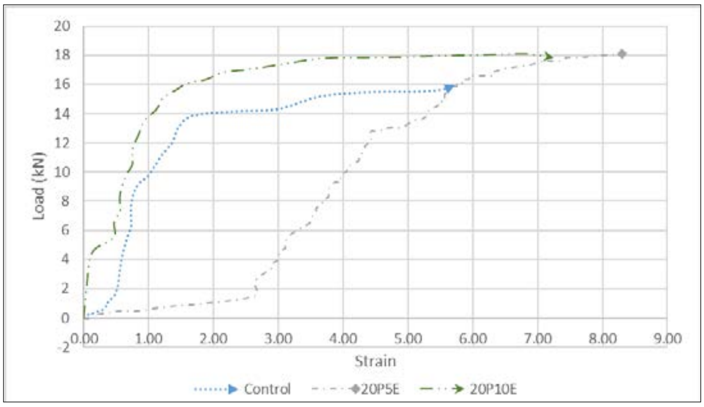
Beam type	Ultimate load (kN)	Average displacement (mm)	Different of displacement against control mix
Control	15.6	4.59	
20P5E	18.0	5.81	+20%
20P10E	18.2	7.25	+36%

3.4 Load vs Strain

The longitudinal strains of the FC-POFA-ES beam specimens were obtained from the measurement using the strain gauges located as Figure 2. The horizontal strain distribution of beam at mid span shows as Figure 6(a) - 6(b).



(a)



(b)

Fig. 6 - Load vs mid-span axial strain (a) - Tension zone; (b) - Compression zone

In terms of the trends in strain, control mix and 20P10E has linear increment within elastic zone until 70% of its respective ultimate load. Meanwhile, the mix 20P5E have non-linear at the first 2.00 strain increment in both zones. This was due combination of irregularities during loading increment and imperfection at the beam surface which caused the hair cracking to occur.

It was observed that the both mixes 20P5E and 20P10E has the higher maximum strain in tension and compression zone compared with control beam. At the ultimate load 18.1kN, mix 20P10E have strain value 7.27 and -3.91 whilst mix 20P5E at the ultimate load 18.0 have strain value 8.30 and -4.11 respectively. Higher strain value on the both mixes compared to control beam was due to higher ultimate load which direct relation toward the ultimate load of beam as suggested by the other researcher (Mohammadhosseini *et al.*, 2016) Addition of 20P10E had shown to more strain resistance against load applied which can be beneficial for beam to resist loading.

3. Conclusion

Inclusion of POFA and eggshell improvised the flexural strength of beam. The experimental and FEA results between concrete mix 20P5E, 20P10E and Control were summarized by 3 key findings. Beam ultimate load capacity, both 20P10E and 20P05E has higher values +14% and +13%. The initial cracks occurs at 6kN which around 39% of ultimate load for each beam. The cracking pattern also recorded has propagated within the flexure zone. The trends in strain for control mix and 20P10E has linear increment within elastic zone until 70% of its respective ultimate load. Meanwhile, the mix 20P5E have non-linear at the first 2.00 strain increment in both zones. This study will be beneficial in construction industry for the application of POFA and eggshell cement replacement materials in normal concrete beam for structural components.

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References

Zhang, J., Liu, G., Chen, B., Song, D., Qi, J., & Liu, X. (2014). Analysis of CO_2 Emission for the cement manufacturing with alternative raw materials: A LCA-based framework. Energy Procedia, 61, 2541-2545.

Aichele, R., & Felbermayr, G. (2012). Kyoto and the carbon footprint of nations. Journal of Environmental Economics and Management, 63(3), 336-354. Construction and Building Materials, 46, 39-47.

Juenger, M. C. G., Winnefeld, F., Provis, J. L., & Ideker, J. H. (2011). Advances in alternative cementitious binders. Cement and Concrete Research, 41(12), 1232-1243.

M. H. Ahmad, R. C. Omar, M. A. Malek, S. Thiruselvam. (2008). Compressive Strength of Palm Oil Fuel Ash Concrete. International Conference on Construction and Building Technology 2008, (27), 297-306.

A. A. Jhatial, G. W. Inn, N. Mohamad, U. J. Alengaram, K. H Mo, R. Abdullah. (2017). Influence of polypropylene fibres on the tensile strength and thermal properties of various densities of foamed concrete. IOP Conference Series: Materials Science and Engineering 271 (1), 012058.

Overview Report of the Malaysian Oil Palm Industry, Malaysia Palm Oil Berhad, (2017).

Yerramala, A. (2014). Properties of concrete with eggshell powder as cement replacement. Indian Concrete Journal, 88(10), 94-102.

Annual Agricultural Report, Ministry of Agriculture and Agro Based, Malaysia. (2017).

Alex, S., & Tiwari, A. (2015). Properties and Applications - A Review. Construction & Building Materials, 15(3), 1869–1894.

Altwair, N. M., Megat Johari, M. A., & Saiyid Hashim, S. F. (2012). Flexural performance of green engineered cementitious composites containing high volume of palm oil fuel ash, 37, 518-525.

K. Abdullah, M.W. Hussin, F. Zakaria, R. Muhamad, Z. A. H. (2006). POFA: A Potential Partial Cement Replacement Material in Aerated Concrete. 6th Asia Pacific Structural Engineering and Construction (APSEC 2006), (September), 5–6.

Muthusamy, K. & Zamri, N.A (2016). Mechanical Properties of Oil Palm Shell Lightweight Aggregate Concrete Containing Palm Oil Fuel Ash as Partial Cement Replacement. KSCE Journal of Civil Engineering, 20(4), 1473-1481. Thakrele, M. H. (2014). Experimental study on foam concrete. International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development, 4(1), 145-158.

Kamaruddin, S., Goh, W. I., Jhatial, A. A., & Lakhiar, M. T. (2018). Chemical and Fresh State Properties of Foamed Concrete Incorporating Palm Oil Fuel Ash and Eggshell Ash as Cement Replacement. International Journal of Engineering & Technology, 7(4.30), 350.

Abd Khalid, N. H., Abdul Rasid, N. N., Mohd Sam, A. R., Abdul Shukor Lim, N. H., Zardasti, L., Ismail, M., … Majid, Z. A. (2019). The hydration effect on palm oil fuel ash concrete containing eggshell powder. IOP Conference Series: Earth and Environmental Science, 220(1).

Tan, J. H., Lim, S. K., Lim, J. H., (2013). Flexural Behaviour of Reinforced Lightweight Foamed Concrete Beams, 1, 1-6.

Müllera, H. S., Breinera, R., Moffatta, J. S., & Haista, M. (2014). Design and properties of sustainable concrete. Procedia Engineering, 95(Scescm), 290-304.

Munir, A., Abdullah, Huzaim, Sofyan, Irfandi, & Safwan. (2015). Utilization of palm oil fuel ash (POFA) in producing lightweight foamed concrete for non-structural building material. Procedia Engineering, 125, 739-746.

Ramamurthy, K., Kunhanandan Nambiar, E. K., & Indu Siva Ranjani, G. (2009). A classification of studies on properties of foam concrete. Cement and Concrete Composites, 31(6), 388-396.

Lim, S. K., Tan, C. S., Lim, O. Y., & Lee, Y. L. (2013). Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler.

Suhendro, B. (2014). Toward green concrete for better sustainable environment. Procedia Engineering, 95(Scescm), 305-320.

Momeen, M., Islam, U., Mo, K. H., & Alengaram, U. J. (2016). Durability properties of sustainable concrete containing high volume palm oil waste materials. Journal of Cleaner Production, 137, 167-177.

Tangchirapat, W., & Jaturapitakkul, C. (2010). Strength, drying shrinkage, and water permeability of concrete incorporating ground palm oil fuel ash. Cement and Concrete Composites, 32(10), 767-774.

Mohammadhosseini, H., Abdul Awal, A. S. M., & Sam, A. R. M. (2016). Mechanical and thermal properties of prepacked aggregate concrete incorporating palm oil fuel ash. Sadhana, 41(10), 1235-1244.