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Mechanical Properties of Lightweight Foamed Concrete with Utilization of Agro-waste as Supplementary Cementitious Material: A Review

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Abstract: Agricultural waste in particular, has been widely used as supplementary cementitious materials (SCM) in concrete production, which help to reduce the carbon dioxide emissions (CO_2) from cement industry. This paper focuses on the effects of palm oil fuel ash (POFA), oil palm ash (OPA) and eggshell powder (ESP) as partial cement replacement on the mechanical properties, workability and water absorption of lightweight foamed concrete (LFC). Previous experimental studies and researches are the credible sources for this review paper. From the findings, most of the reviews proved that utilization of these agro-waste powders could improve the compressive strength, flexural strength and splitting tensile strength of LFC. From overall reviews, it found that presence of agro-waste in LFC caused a reduction in the workability and water absorption. The optimum percentage ranges for POFA or OPA was 20% to 30% and for ESP was 5% to 7.5%. Meanwhile, up to 25% of combined POFA and ESP have proven to enhance the strength properties of LFC.

Keywords: Agricultural Waste, Supplementary Cementitious Material, Lightweight Foamed Concrete, Mechanical Properties

1. Introduction

Lightweight foamed concrete (LFC) is composed of cement, sand and water with added foam. Nowadays, LFC is getting popular in construction field due to its low self-weight that can reduce the dead load of structure, relatively high strength that can withstand the applied load to the structure, good

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thermal insulation that can low the thermal conductivity of the structure, and the excellent sound insulation that can preclude the noise [1].

In Malaysia, waste is one of the environmental issues that need to be tackled with effective methods. The climate in Malaysia is tropical rainforest, which is hot, rainy and humid the whole year. This climate is very suitable for various agricultural activities. The amount of agricultural waste that is generated yearly in Malaysia is approximately 998 million tonnes while 1.2 million tonnes of them are disposed of into the landfill [2]. This scenario causes the shortage of landfill as well as the numerous environmental issues especially water and lake pollution. Another environment problem that need to be conquered is carbon dioxide (CO_2) from the cement industry. Cement is a main constituent material in concrete production. However, it is also a significant contributor to the CO_2 emissions, which are the key sources of greenhouse gases that lead to global warming.

Construction industry has the greatest responsibility to achieve sustainability in the construction field. LFC with agro-waste is one of the alternatives to increase sustainability in the construction sector. Utilisation of agricultural wastes as supplementary cementitious materials (SCM) can help to eliminate the negative impact on the environment such as reducing the amount of agricultural waste and CO_2 emissions.

This paper highlighted the effects of oil palm waste ash and eggshell waste powder as partial cement replacement on the mechanical properties included compressive strength, flexural strength and splitting tensile strength of LFC. Optimum percentage of these two agro-waste powder or ash that required replacing the cement in LFC was determined in this study by referring to several reliable reviews. In addition, workability and durability tests such as slump test and water absorption were addressed as well in this comprehensive review. Through this review study, usage of LFC with added agricultural waste as sustainable construction materials can be promoted in the construction sector in order to reduce the abundance of agro-waste issues and CO_2 emission from the cement production. Besides, this study had a significant contribution to the reduction in high demand of cement, which caused a high material cost in the construction field.

2. Oil palm waste

Palm oil industry is a significant contributor to the economy of Malaysia since Malaysia is honoured as the second-largest exporter of the palm oil in the world. Nevertheless, this industry increases a huge amount of agricultural waste. For instance, palm oil fruit bunches, fibres and kernel shells. POFA is suitable used as a partial cement replacement in concrete production due to its high content of silica in POFA that possess the criteria of pozzolanic properties that can enhance the strength and durability of concrete [3]. Tambichik *et al*., [4] reported that 47% to approximately 65% content of silica in POFA enables it to replace the cement partially in concrete. A secondary C-S-H gel is produced as the reaction of calcium hydroxide, $Ca(OH)_2$ with cementitious elements takes place. Table 1 presents the chemical composition of POFA.

Table 1: Chemical composition of POFA [5]

Chemical Composition	%
SiO_2	57.71
Al_2O_3	4.56
Fe_2O_3	3.30
CaO	6.55
MgO	4.23
Na_2O	0.50
K_2O	8.27
SO^3	0.25
LOI	10.52

3. Eggshell waste

Eggshell is considered as one of the agricultural waste that was generated abundantly from the farming activities. The Department of Veterinary Services (DVS) Malaysia reported that approximately 11906 million eggs were consumed in 2016 and predicted to increase to 12235 million in 2017. This leads to the huge amount of eggshell produced. Tiong *et al*., [6] stated that the proportion of eggshell that consist of calcium carbonate, magnesium carbonate, calcium phosphate, organic matter and other insoluble proteins are 94%, 1%, 1% and 4% respectively. High content of calcium carbonate in eggshells can assist the acceleration of tricalcium silicate (C_3S) and cement hydration. Table 2 displays the chemical composition of ESP.

Table 2: Chemical composition of ESP [7]

Chemical Composition	%
SiO_2	1.63
Al_2O_3	-
Fe_2O_3	0.05
CaO	88.76
MgO	0.91
K_2O	0.24
SO_3	0.81
LOI	7.6

4. Review of previous studies

The reviews conducted on previous research studies in this paper mainly focuses on three main waste materials; namely POFA, OPA and eggshell powder. The findings from the each research was gathered, analyzed and summarized in the following tables and paragraphs.

Table 3: Summary of each previous research

Author	Agricultural waste used as SCM	Replacement level (%)	Curing ages (day)	Findings
Alnahhal *et al*., [8]	POFA	0%, 10%, 20% and 30%	3, 7 and 28	● Negative effects of POFA in LFC on compressive strength and splitting tensile strength of LFC were performed.
Jhatial *et al*., [9]	POFA + ESP	POFA (0 – 25%) and ESP (0-15%)	7 and 28	● 25% of POFA combined with 5% of ESP obtained the strongest compressive strength while 20% of POFA and 5% of ESP achieved the maximum splitting tensile strength. ● Increasing the POFA and ESP content in LFC resulted in the reduction in workability.
Jhatial *et al*., [7]	POFA + ESP	POFA (0 – 35%) and ESP (0 – 15%)	7 and 28	● The maximum compressive strength was obtained by foamed concrete that included 30% of POFA and 5% of ESP at 28 days, which was 19.25 MPa. ● Adverse effect was observed on the splitting tensile strength.

Table 3: (continued)

Tiong *et al*., [10]	ESP	0%, 2.5%, 5.0%, 7.5% and 10%	28	● Replacement level at 5% of ESP had achieved the highest compressive strength of LFC at 28 days, which was considered as optimum percentage.
Rahman, Goh & Jhatial [11]	POFA + ESP	20% of POFA and 5% to 10% of ESP	28	● Up to 20% of cement replacement in reinforced foamed concrete beams achieved higher flexural strength than that of control beam specimen.
Tiong *et al*., [6]	ESP	0%, 2.5%, 5.0%, 7.5% and 10%	28	● Optimum percentage of partial cement replacement was 5% of ESP. ● Workability of LFC specimens decreased as the content of ESP increased. ● Slightly increment in water absorption was indicated when the amount of ESP increased in LFC.
Arminda & Awang, [12]	POFA	0%, 20%, 30%, 40%, 50% and 60%	7, 14, 28, 56 and 90	● LFC with 20% of added POFA achieved the highest compressive strength at all curing ages among others. ● LFC with POFA at dosage of 20% achieved the lowest porosity compared to other mixtures. This caused a reduction in water absorption.
Arminda & Awang, [13]	POFA	0%, 30% and 50%	7, 14 and 28	● LFC with 30% of POFA obtained the highest compressive strength among others at all curing ages. ● High amount of POFA content in LFC resulted in a high porosity.
Awang & Al-Mulali, [14]	OPA	0%, 25%, 35%, 55% and 65%	7, 14, 28 and 56	● 25% of OPA was the optimum percentage that could enhance the strength properties of LFC.
Lee, [15]	ESP	0%, 2.5% and 5.0%	7. 28 and 90	● ESP with inclusion level at 5.0% indicated the best performance indexes in the compression test. ● Lower water absorption and porosity percentage were obtained as the ESP content added in LFC.
Tiu, [16]	ESP	0% and 7.5%	7, 28, 56, 90 and 180	● Positive effects on compressive strength, flexural strength and splitting tensile strength were performed as 7.5% of ESP was used as a cement substituent in LFC. ● Presence of 7.5% of ESP in LFC caused an increment in water absorption.
Awang *et al*., [17]	OPA	0%, 25%, 35%, 55% and 65%	7, 14 and 28	● OPA at 35% gained the most compressive strength at 28 days. ● The highest splitting tensile strength obtained by mix OPA25. ● Negative effect on flexural tensile strength was observed.

The findings from previous research are discussed in the following sections according to the waste materials utilized as replacement.

4.1 Palm oil fuel ash (POFA) or oil palm ash (OPA)

Alnahhal *et al*., [8] found that the utilization of POFA in LFC caused the negative effects on the compressive strength and splitting tensile strength of LFC In this research, 20% of POFA as SCM performed slightly better compressive strength than another two replacement levels of POFA, which were 10% and 30%. However, it got a lower compressive strength as compared to the control mix. Adverse effect on the splitting tensile strength was found in this study as well. This possibly affected by less fineness of POFA that weaker the pozzolanic activity and thus weaker the strength. Besides, low water to cement ratio used in this study was quite low, which was 0.35, result in poor dispersion in water between the cement particles and thus influence the pozzolanic reaction during the process of hydration.

In contrast, positive result was discovered in the study of Arminda & Awang, [12] . LFC with 20% of added POFA achieved the highest compressive strength at all curing ages among others. It reported that the reduction in compressive strength by using 60% of POFA as substitution for cement is obvious. This occurrence was affected by the increment in water to solid ratio during the process of mixing. Moreover, LFC included 20% of POFA as SCM was the only mixed proportion that gained lower water absorption value than that of control specimens due to it possesses the lowest porosity percentage.

The results of Arminda & Awang, [13] indicated the compressive strength of LFC incorporated with POFA at dosage of 30% performed better than that of control mix. This caused by a large amount of calcium silicate hydrate (C-S-H) produced by the pozzolanic reaction and 5% of fine silica fume was added into the foamed concrete mixtures. For the slump test, the spread diameter of normal foamed concrete mixtures, foamed concrete mixtures with 30% and 50% of POFA are 200 mm, 180 mm and 185 mm respectively. From the results, it could be concluded that LFC incorporated with POFA caused a reduction in workability.

Findings of Awang & Al-Mulali, [14] is another case that has successfully proved that the oil palm ash (OPA) as partial cement replacement is able to improve the mechanical properties of LFC. OPA with 25% as SCM in LFC possessed the best strength performance in terms of compressive strength, flexural strength and splitting tensile strength when compared to other mixtures. The highest compressive strength, flexural strength and splitting tensile strength at 28 days were 6.50 MPa, 2.0MPa and 0.80 MPa respectively. This result was contributed by the addition of superplasticizer with 1% in the mixtures.

Awang *et al*., [17] found that LFC incorporated with OPA at 35% obtained the highest value of compressive strength 7.89 MPa at 28 days. However, the deterioration of strength occurred as the replacement level of OPA increased. This is because a high amount of OPA in LFC reduces the CaO content from cement and thus affect the pozzolanic reaction to produce extra C-S-H gel for the strength enhancement. At 28 days, OPA with 25% attained 0.72 MPa of the strongest splitting tensile strength among others. This was because adequate cement content and less water is required due to low water/solid ratio. However, this research found that including the OPA in LFC caused the flexural strength decreased from 1.87 MPa to 1.80 MPa, which was 3.89% of decrease, but still considered as an acceptable value.

From overall reviews, it can be said that inclusion of oil palm waste ash in LFC develops the strength properties, causes a reduction in workability and water absorption. As stated earlier, oil palm waste ash consists of high amount of silica in its chemical composition, which is very suitable to be used as SCM in concrete production.

4.2 Eggshell powder (ESP)

Tiong *et al*., [10] carried out the compression test of LFC with densities of 1000 kg/m^3 and 1400 kg/m^3. The optimal water to cement ratio for these two densities were 0.64 and 0.60 respectively. In the comparison on both densities, compressive strength of LFC at 1400 kg/m^3 obtained the higher value than that of LFC at 1000 kg/m^3. This is owing to the denser concrete specimen possesses less pore sizes which is able to make the internal structure of cement paste stronger. The water absorption for 1000 kg/m^3 of LFC specimens was higher than the water absorption for 1400 kg/m^3 of LFC specimens. It was because the high porosity and large void in less dense specimens, so the specimens would absorb more water as it submerged.

Tiong *et al*., [6] found that the optimum percentage for ESP replacement in LFC was 5%. This paper also discovered that the compressive strength at 7 days was lower than that at 28 days. This is caused by the content of C_3S had been diluted by ESP and slower reaction of ESP occurred during the hydration process. Besides, inclusion of ESP at 5% in beam specimens at 28 days had improved the flexural strength by 3.46%. However, reduction in workability occurred as the inclusion level of ESP increased. 10% of ESP as partial cement replacement in LFC obtained the largest value of water absorption among others. This is due to high water demand in LFC that lead by the high content of ESP, which resulted in a high tendency of foamed concrete specimens to absorb the water during submersion.

The research by Lee, [15] also noticed that ESP with 5% of replacement in LFC was the optimum percentage. It also revealed that the water absorption of LFC was greatly reduced by including 5% of ESP, which was 20.99%. This is because the void in concrete can be filled with the presence of ESP and this can weaken the ability of foamed concrete mixtures to absorb the water during the process of submersion [18].

The replacement percentage of ESP used in the study of Tiu, [16] were 0% and 7.5%. This paper revealed that utilization of ESP at 7.5% in LFC could bring the positive effects on compressive strength, flexural strength and splitting tensile strength. For the water absorption, the percentage of water absorption and porosity of LFC involved ESP content at 7.5% were higher compared to the reference mix. For this, porous structure and fineness of ESP are the main factors that caused such results. Furthermore, LFC that involved excessive amounts of ESP will cut down the cement content and lead to an increment in water requirement. Consequently, the specimens have a low resistance to water absorption.

As a conclusion, engineering properties of LFC could be improved by 5% of ESP. Calcium-rich in ESP can assist the acceleration of tricalcium silicate (C_3S) and cement hydration. Furthermore, reduction in workability and water absorption were found according to overall reviews. It is suggested to add superplasticizer in concrete mix in order to increase the workability.

4.3 Combination of POFA and ESP

Jhatial *et al*., [9] utilized the POFA and ESP as SCM simultaneously to evaluate the effect on LFC's mechanical properties. The substitution levels for POFA and ESP in LFC were in the range of 0% to 25% and 0% to 15% respectively. The compressive strength of 25% of POFA and 5% of ESP at 28 days was recorded as 22.6 MPa, which was the highest compressive strength. Besides, this paper found that inclusion of POFA along with ESP can significantly improved the splitting tensile strength of LFC. From the results, mix design with 20% of POFA along with 5% of ESP achieved the highest value of splitting tensile strength, which was 2.61 MPa. This is because ESP is calcium-rich material while POFA is silica-rich material. Presence of ESP allow POFA can consume the additional $Ca(OH)_2$ during pozzolanic reaction, which is good for strength development.

Jhatial *et al*., [7] performed the compression test of LFC with the combined POFA and ESP. Combination of 30% of POFA and 5% of ESP as SCM in LFC specimens indicated the highest compressive strength as compared to other mix proportions, which was equal to 19.25 MPa at 28 days. However, it also revealed that the tensile strength of LFC containing POFA and ESP was not significantly improved. This was because foamed concrete specimens included POFA and ESP possessed ineffective interfacial transition zone (ITZ) between fine aggregate and binder matrix.

Rahman *et al*., [11], found positive result on the flexural strength test. Reinforced foamed concrete beams with 20% of POFA and 5% of ESP as well as 20% of POFA plus 10% of ESP were involved in the flexural strength test. From the result, both beam specimens had the higher flexural strength than that of control beam specimens. With the cooperation of POFA and ESP, the flexural strength can reach up to 9.2MPa. Other than the pozzolanic reaction that is triggered by combined POFA and ESP in foamed concrete beam specimens, this study applied the doubly reinforcement in beam specimens for the flexural strength enhancement.

In conclusion, addition of POFA and ESP simultaneously in LFC can bring a positive effect on the mechanical properties. This is because ESP provide extra $Ca(OH)_2$ for POFA to consume during pozzolanic reaction and thus develop the strength of LFC.

5. Analysis and discussion

5.1 Compressive strength

Compressive strength of LFC included oil palm waste at 7 days and 28 days from each reviews is represented in Figure 1. The optimum percentage of oil palm waste powder or ash from five researches are in the range of 20% to 30%. LFC in the study of Awang & Al-Mulali, [14] gained the maximum 6.00 MPa and 6.50 MPa of compressive strength at 7 days and 28 days by 25% of OPA. This is due to the hardened density of specimens in this study is denser than other studies, which is around 1450 kg/m^3 for each specimens. Theoretically, denser specimen possesses a stronger internal structure in cement paste because of the lesser pore size.

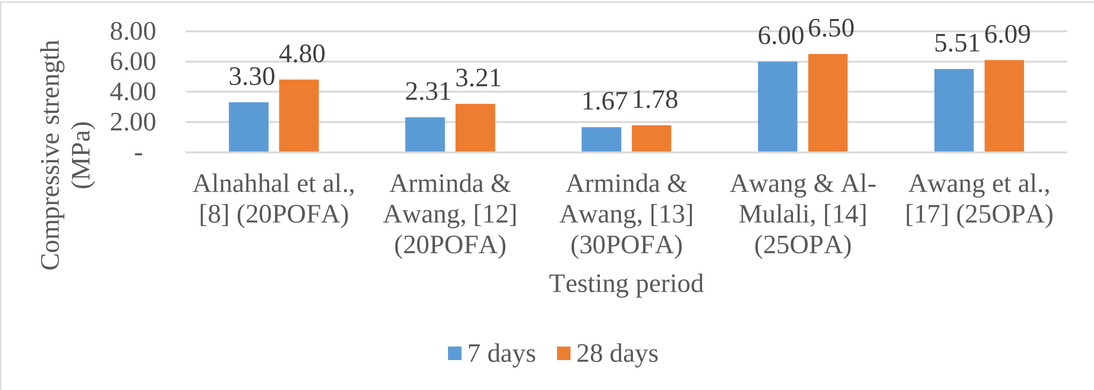

Figure 1: Compressive strength of LFC with added oil palm waste powder or ash among studies

Figure 2 indicates the compression test results at 7 and 28 testing periods by Tiong *et al.*, [6], Lee, [15] and Tiu, [16]. The highest compressive strength for 7 and 28 days are 5.46 MPa and 6.53 MPa respectively. The optimal w/c ratio for Tiong *et al.*, [6], Lee, [15] and Tiu, [16] were 0.60, 0.56 and 0.56 repectively. W/c ratio is one of the signicant factor that affect the strength properties of concrete. Therefore, it is highly recommended to conduct the necessary test to get the optimal w/c ratio initially before the compression test. This can help to increase the accuracy in results. Three reseaches have concluded that including the ESP by 5% to 7.5% can strengthen the foamed concrete.

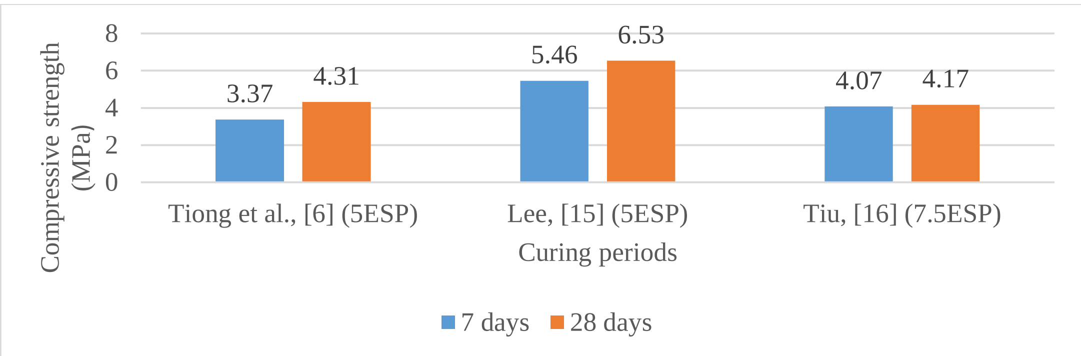

Figure 2: Compression test results between previous studies

Figure 3 displays the compression test results at curing ages of 7 and 28 from two researches. Maximum compressive strength at 7 days and 28 days are obtained by 25% of POFA along with 5% of ESP in the study of Jhatial *et al*., [9], which are 18.55 MPa and 22.60 MPa respectively. Between both studies, the inclusion level of POFA that was used by Jhatial *et al*., [7] was 5% higher than Jhatial *et al*., [9]. In general, excessive content of agricultural waste powder or ash in concrete decreases the cement content. Consequently, this lead to an issue on the availability of $Ca(OH)_2$ from cement for the accessible silica in POFA during the hydration process and thus affects the transformation of secondary C-S-H gel. Hence, lower compressive strength was gained at 7 days and 28 days in the study of Jhatial *et al*., [7].

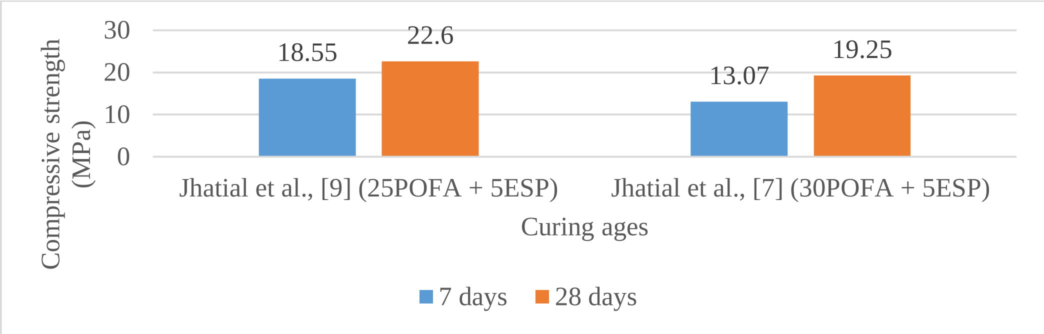

Figure 3: Compression test of LFC with combined POFA and ESP among previous studies

5.2 Flexural strength

Figure 4 displays the recorded flexural strength values in the studies of Awang & Al-Mulali, [14] and Awang *et al*., [17]. Flexural strength in the research of Awang *et al*., [17] at both curing ages are slightly lower than that of the flexural strength in the study of Awang & Al-Mulali, [14]. The plastic density of specimens used affects this result. Density of the specimens in the studies of Awang & Al-Mulali, [14] and Awang *et al*., [17] were 1450 kg/m^3 and 1300 kg/m^3 respectively. In general, the pore size inside the denser specimen is smaller when compared to the less dense specimen. Hence, denser specimens gain higher strength than less dense specimens.

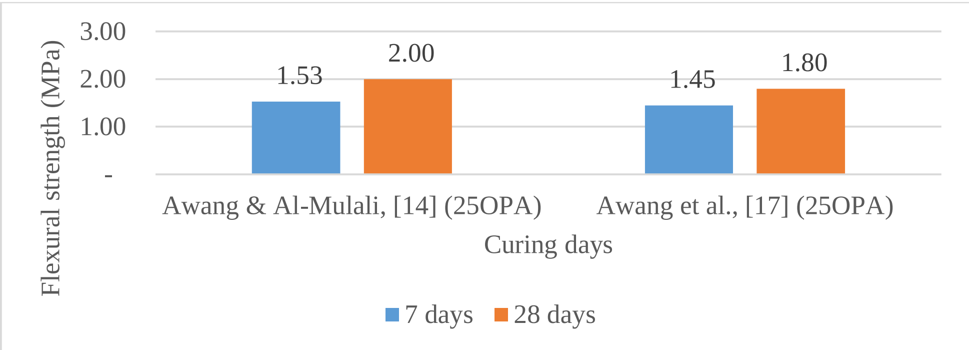

Figure 4: Flexural strength of LFC incorporated with oil palm waste among previous researches

Flexural strength of LFC with added ESP among previous studies is shown in Figure 5. Both studies have concluded that flexural strength of LFC can be improved with the utilization of ESP as SCM. This is due to the chemical composition of ESP is nearly identical to the limestone, which both are known as the calcium-rich materials. Reaction between limestone and alumina cement pastes form calcium mono-carboaluminate and increase the hydrates volume caused by the increment in quantity of ettringite. This can minimize the porosity and thus enhance the strengths of concrete at the same time [19].

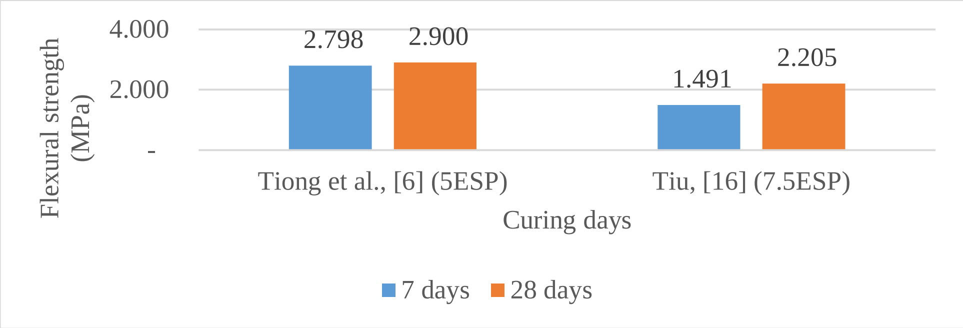

Figure 5: Flexural strength of LFC with included ESP between studies

Meanwhile, with the cooperation of POFA and ESP, Rahman *et al.*, [11] is the only study that carried out the flexural strength test to evaluate the effects of this two agricultural waste types as partial replacement of cement simultaneously in LFC. From the result, the flexural strength could reach up to 9.2 MPa as the cement in LFC partially replaced by the combined POFA along with ESP. Other than the pozzolanic reaction that was triggered by combined POFA and ESP in foamed concrete beam specimens, this study also applied the doubly reinforcement in beam specimens for the flexural strength enhancement.

5.3 Splitting tensile strength

Figure 6 shows the splitting tensile strength values from three researches. Study of Alnanhal *et al.*, [8] only conducted the splitting tensile strength test on 28 days. Among three researches, flexural strength value in the study of Alnanhal *et al.*, [8] obtained the lowest value due to low w/c ratio was used in this study, which was 0.35. Low w/c ratio brings about the poor dispersion in water among the cement particles and causes a negative effect on the pozzolanic reaction during the process of hydration. As a result, it affects the strength development.

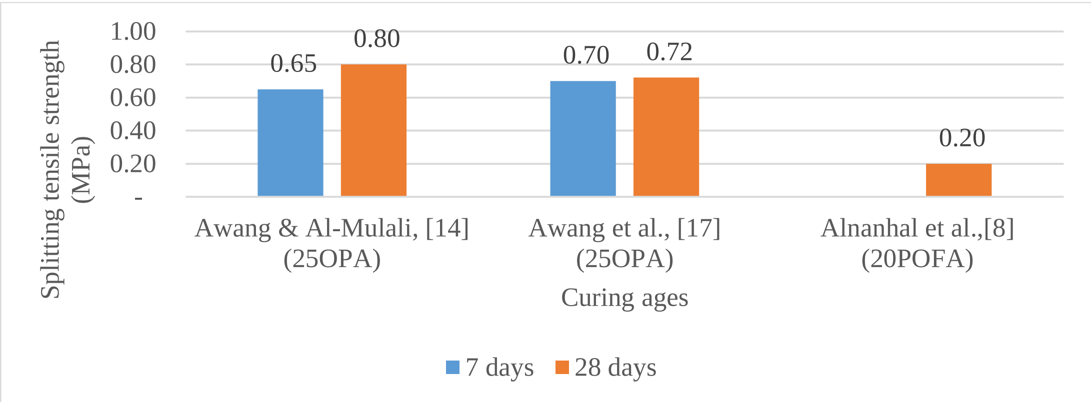

Figure 6: Splitting tensile strength of LFC with added oil palm waste ash between researches

For ESP, Tiu, [16] is the only researcher who have investigated the effects of ESP as SCM on mechanical properties of LFC. From the results, the splitting tensile strength was increased from 0.522 MPa at 7 days to 0.60 MPa at 28 days. In general, strength was developed with the increasing of curing ages. This is because C-S-H gel that able to strengthen the concrete is continuously produced during the hydration process. This study concluded that inclusion of ESP able to enhance the splitting tensile strength of LFC.

Figure 7 illustrates the splitting tensile strength test results for the studies of Jhatial *et al.*, [9] and Jhatial *et al.*, [7]. When adding the POFA and ESP simultaneously in LFC mixtures, the splitting tensile strength is much higher than replacing the cement by only POFA or ESP separately. This is owing to the provision of additional CaO by ESP allows the consumption of extra $Ca(OH)_2$ for POFA during pozzolanic activity and thus strengthens the strength. Study of Jhatial *et al*., [9] achieved higher flexural strength than study of Jhatial *et al*., [7]. This is reasoned to the higher content of POFA used in the research of Jhatial *et al*., [7] decreases the amount of cement. This causes the shortage of $Ca(OH)_2$ and thus influences the pozzolanic activity.

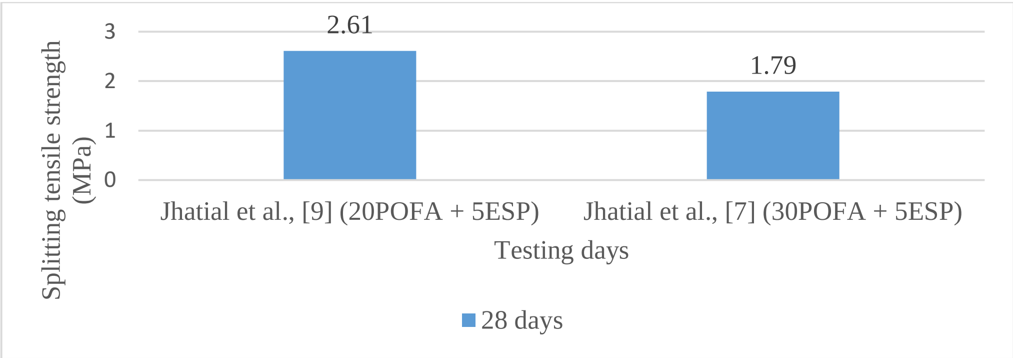

Figure 7: Splitting tensile strength test results among previous studies

5.4 Workability

All researches have outlined that the addition of POFA and ESP content result in the reduction in workability of LFC. This is reasoned to the high porosity of ESP that leads to more water being absorbed by ESP than cement [10]. Moreover, the grinding that increases the surface area of POFA while reducing the particle size will reduce the workability of concrete mix [20]. Increasing the workability of concrete causes a reduction in the strength of concrete. Deterioration of concrete's strength can be affected by either insufficient water content or excessive water content in the mixtures. Thus, it is necessary to find the optimum water to cement ratio to achieve an equilibrium between the workability and strength of concrete.

5.5 Water absorption

Overall findings have concluded that presence of POFA and ESP are able to minimize the absorption of water in LFC. Tiong *et al*., [10], Arminda & Awang, [12], Alnanhal *et al*., [8] and Lee, [15] declared that water absorption of concrete mix could be affected by the porosity and oven-dry density. Theoretically, larger pore sizes make the cement paste less denser and thus increase the absorption of water. Most researchers discovered that POFA at 20% reduced the most in water absorption. Involvement of POFA in LFC triggered the pozzolanic reaction and this altered the structures in pore sizes of the mix [21]. Consequently, refinement in pore sizes happened. Meantime, the existence of ESP in LFC possessed a high efficiency to reduce the water absorption. Generally, ESP is adopted as an inert filler due to it possessing up to 95% of calcium in the chemical composition [18]. Strength properties of a foamed concrete are affected indirectly by the water absorption. Thus, it is very important to carry out the water absorption test to measure the durability of a foamed concrete incorporated with agro-waste.

5.6 Optimum percentage

Previous researchers have recorded various optimum percentages of agro waste powder as partial cement replacement in LFC. The variety of optimum percentages was due to various targeted strength, types of density of concrete used and other replacements/additives included in the mixture. The following paragraphs discusses about the optimum percentage of oil palm waste ash and eggshell waste powder as SCM between previous studies.

Figure 8 indicates the optimum percentage for oil palm waste ash to replace the cement partially in LFC from all previous studies. The optimum percentage of POFA or OPA are in the range of 20% to 30%. It can be said that utilization of POFA as partial cement replacement has a high potential to improve the mechanical properties of concrete production since high content of silica in it can enhance the pozzolanic activity by producing the C-S-H gel during cement hydration process.

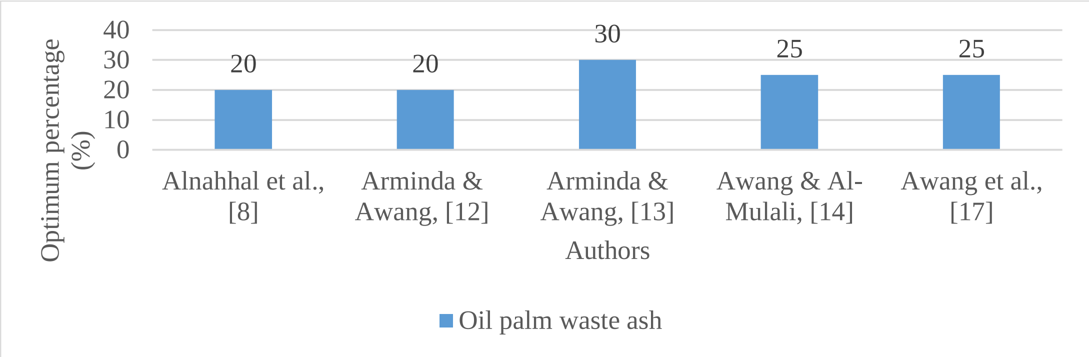

Figure 8: Optimum percentage of oil palm waste ash

Figure 9 illustrates the optimum percentage of ESP as SCM in LFC from all authors. LFC included ESP at 5% to 7.5% able to acquire stronger strength properties than that of the reference specimens. Improvement in the reaction between silica and calcium oxide, which are from the cement and ESP respectively, can help to generate additional C-S-H gel during the cement hydration process. Furthermore, high contribution of ESP as a void filler capable of making the internal structure of concrete stronger [22].

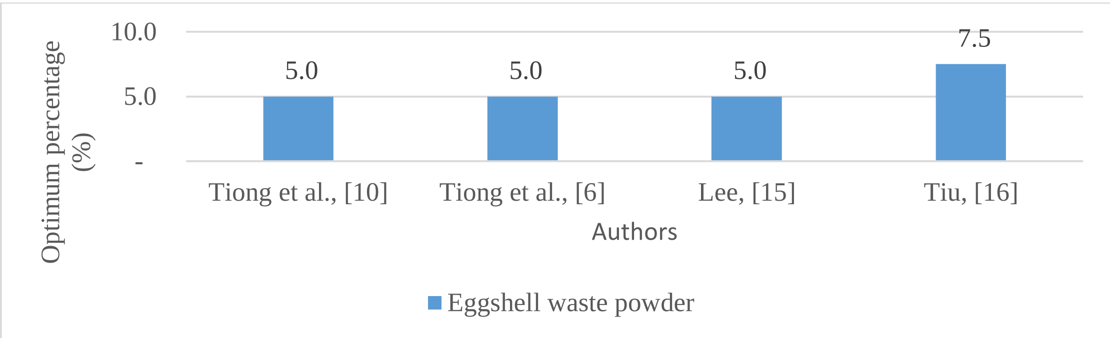

Figure 9: Optimum percentage of eggshell waste powder

Optimum percentage of combination of POFA and ESP from all studies is presented in Figure 10. For the utilization of combined POFA and ESP in LFC as SCM, up to 25% of cement replacement by combination of these two agricultural wastes powder or ash can develop the mechanical properties of LFC. Incorporation between silica-rich POFA and calcium-rich ESP as SCM in LFC is able to trigger stronger pozzolanic activity and thus develop stronger strength properties.

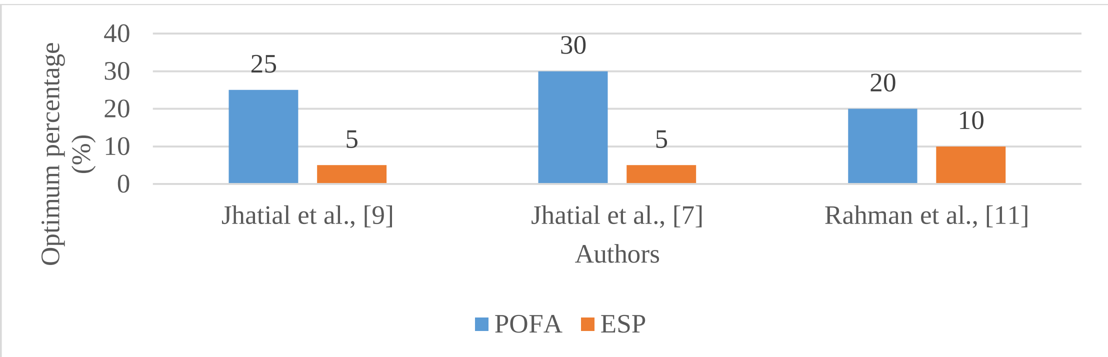

Figure 10: Optimum percentage of combined POFA and ESP

6. Conclusion

From the overall reviews, the results indicated that addition of POFA or OPA and ESP have a high efficiency to improve the strength properties of LFC. Besides, Most of the research reported that including agricultural waste powder or ash caused the reduction in workability and water absorption. Overall reviews reported that the optimum percentage ranges for POFA or OPA was 20% to 35% and for ESP was 5% to 7.5%. Meanwhile, for the combined use of POFA and ESP in LFC, strength properties can be enhanced by up to 25% of combined partial cement replacement level. As a conclusion, the objectives of this comprehensive review study were achieved.

It is highly recommended to conduct the review study on the effect of agricultural waste other than oil palm waste and eggshell waste on the engineering properties of concrete production. For example, rice husk ash (RHA), sugarcane bagasse ash (SCBA) and banana shell powder (BSP). This aims to find the highest efficiency to improve the strength properties of concrete among various agricultural wastes as well as to reduce the amount of wastes and CO_2 emissions that cause the negative impacts on the environment.

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