The Influence of Palm Oil Fuel Ash and Metakaolin on The Strength of Concrete and Crack Resistance of Reinforced Concrete Beam: A Review

Fatimah De'nan[1*], Megat Azmi Megat Johari[2], Shaneez Christie Anak Nyandau[3] and Nor Salwani Hashim[4]

[1,2,3,4]School of Civil Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Pulau Pinang, Malaysia

[1]cefatimah@usm.my, [2]cemamj@usm.my, [3]shaneezchristie@gmail.com and [4]wani_a02@yahoo.com

Abstract

Purpose An Ordinary Portland Cement (OPC) has been used in the concretes production where it is an important material to be considered due to its nature that react with every substance present. During the cement production, a significant amount of carbon dioxide is emitted from the clinker in rotary kiln and lot energy is required in the production processes. Such an event can be prevented by replacing the part of cement with Metakaolin (MK) and Palm Oil Fuel Ash (POFA). Aside from being a cementitious alternative, the materials can also contribute to a greener environment and more sustainable building, as POFA is available in Malaysia and may be used to substitute cement and minimize pollution.

Methodology The study assesses the effect of MK and POFA on the concrete in terms of compressive strength and cracks pattern of the reinforced concrete beam based on the relevant previous studies.

Findings From this study, the compressive strength of concrete containing MK and POFA was higher than the control mix with the percentage of improvement in the range of 0.8% to 78.2% for MK and 0.5% to 14% respectively. The optimum content of MK and POFA is between the range of 10% to 15% and 10% to 20% respectively to achieve high strength of concrete. Other than that, the inclusion of MK to the concrete mix improves the strength of reinforced concrete beams and reduces cracks on the surface of reinforced concrete beams, whereas the inclusion of POFA to the concrete mix increases the cracks on reinforced concrete beams. The cracks appeared within the flexure zone of every beam containing the MK and POFA.

Value It was found that the fineness of MK and POFA has a significant influence on the mechanical properties of concrete.

Keywords: concrete, reinforced concrete beam, metakaolin, palm oil fuel ash, strength

1 Introduction

Concrete, as one of the materials used in building construction, is a porous material, and its physical and mechanical properties gives an important role in determining the materials strength (Krishna et al., 2021) and toughness, as well as the characteristics of concrete in building structural members such as beams. Some of the similarities in certain of the concrete types are the materials used to produce the concrete. Cement, aggregates, and water are the main materials in traditional concrete. Many improvement techniques have been implemented in the recent years to create an excellent concrete that saves energy and money. Such methods are needed to increase the concrete production. In this work, cement in the concrete was replaced in order to strengthen the concrete.

Metakaolin (MK) and Palm Oil Fuel Ash (POFA) are the two materials that have been introduced and analysed for many years. These materials have been used in a range of industries, including the construction of industrialized buildings and the medical industry. To minimize the porosity of the concrete, the materials were added to the mix as an additive and as cementitious substitute materials. Besides that, concrete porosity can be minimized by mixing cement with a pozzolana additive like Metakaolin (Mohd Sam et al., 2017). Metakaolin and POFA have been used in concrete and give an improvement to the mechanical properties of the material (Siddique and Klaus, 2009).

Aside from additives, the effect of application of concrete mixtures to structural behavior has been studied for a long time to see whether the mixtures substance can give an impact and diffusion to the high velocity flow in the mass of water (Nigam et al., 2015). In addition, the effects of micro-silica gels (AP2RC and P1RB) led to increased tensile, compressive and flexural strength values for the concrete strength characteristics during early ages as well as ultimate ones with the resulting reduction in the porosity lowering permeability of the micro-silica concrete (Seyed Mehdi et al., 2016). Besides that, the stability that reflected to reduce aggregate segregation is achieved by using the mixture of recycled concrete aggregate (RCA) and polypropylene fibers (PPF) (Matar and Assaad, 2019). Also, simultaneous use of 25% glass and 1.5% polypropylene fibers results in best flexural and compressive strengths of concrete (Orouji et al., 2021).

Further to that, physical properties of the concrete and the chemical composition change considerably which dehydration of water from calcium silicate hydrate becomes critical at above 110^{o}C (Demiral and Kelestemur, 2010). For self-compacted concrete, the compressive strength increased at150^{o}C and decreased continuously after this temperature.

2 Systematic Literature Review (SLR) Methodology

Two key of methodological methods have been established for this work. The first goal was to assess the compressive strength of concrete with MK and POFA. A systematic literature review (SLR) was conducted. Secondly, a systematic literature review was conducted to determine the cracking behavior of concrete beams where MK and POFA were used as partial replacement of the cement.

A systematic review is a well-defined and methodological procedure that classifying, analyzing, and synthesizing the available evidence for a particular technology in order to explain the current course and status of research or provide background information on research challenges (BA and Charters, 2007). The SLR review protocol is described in this section. The SLR steps as shown in Figure 1 were used to show the existing literature on experimental and numerical research on the crack pattern of reinforced concrete beams with POFA and MK.

In this study, there are a few steps that have been carried out to complete the systematic literature review (SLR). Firstly, three review questions were identified from the review topic such as how the compressive strength of concrete are affected by the utilization of MK and POFA, how the cracking behavior of reinforced concrete beam affected by the utilization of MK and POFA and what is the optimum content of MK and POFA to produce high compressive strength of concrete. After identifying review question, some searching strategies are identified for the review question such as identify synonyms, related phrases and keyword variants and screening, defines the inclusion and exclusion requirements for the papers. Then, collect and extract all the relevant data for the review questions. Next step is defining data synthesis. Last but not least, combine the data from a number of review articles in order to draw conclusions about the research topic.

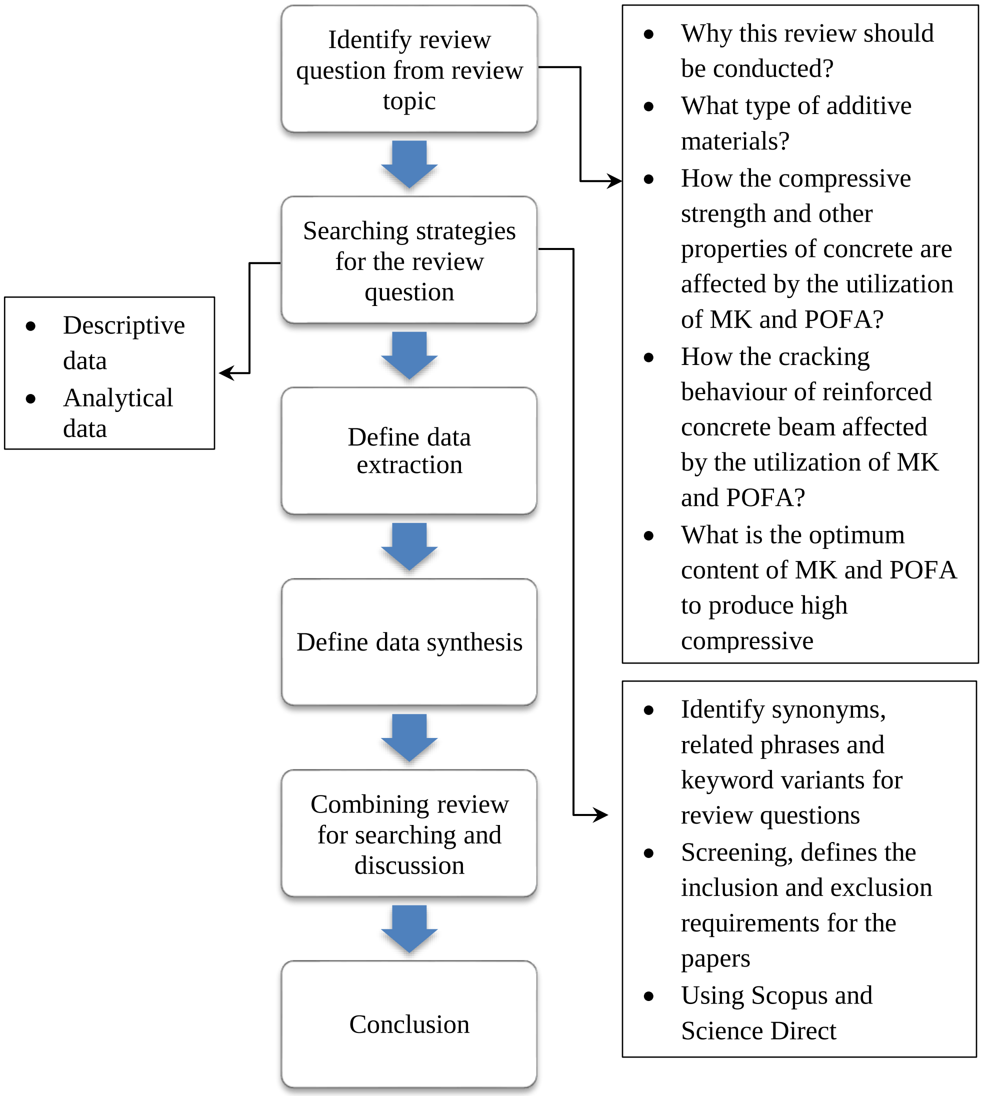


Figure 1 Methodology for systematic review

3 Findings and Discussion

3.1 Effects of MK on compressive strength of concrete

MK is a pozzolanic additive or product that can offer a variety of benefits. The binding capacity or free lime will be determined by purity. Some of them also have a high level of responsiveness. MK is a useful additive for use in concrete and cement. Furthermore, MK can refine the porosity of the cement paste (McCarthy and Dyer, 2019). In the recent years, there has been a surge interest in using MK as a cement substitute.

According to other research (Brooks and Megat Johari, 2001) where 0%, 5%, 10% and 15% of MK are used, compressive strength improves when the amount of incorporation of MK increases, with 10% MK demonstrating the greatest value of compressive strength by 19.54% from compressive strength of control mix, as illustrated in Figure 2. In addition, a research on mechanical properties of high-strength concrete containing Metakaolin (which is 0% - 50% of MK as cement replacement) and hybrid fibres inclusion by volume has been carried out (Shehab El-Din et al., 2017). It was found that the compressive strength increased about 16% to 22% than control mix for range of 10% and 15% MK and it started to decrease when using 20% of MK and above as shown in Figure 3. For the research on mechanical properties of self-compacting concrete blended with MK, it was observed that compressive strength of cement containing MK increased between the range of 80 MPa to 90 MPa for 10% and 20% of MK which is higher than the control concrete mixture (50 MPa to 60 MPa) (Dadsetan and Bai, 2017).

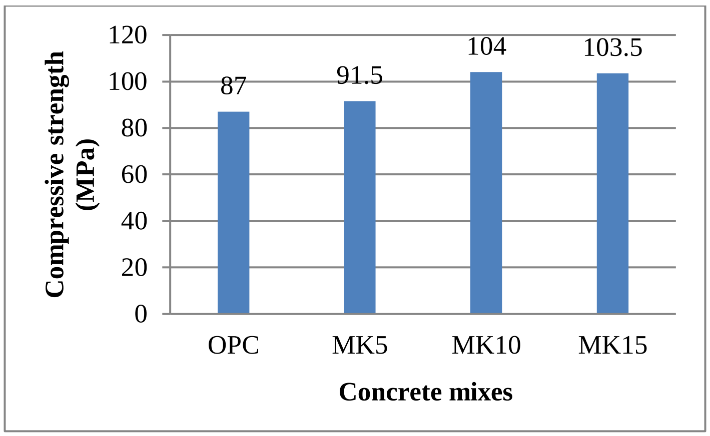


Figure 2 Compressive strength of concrete containing MK (Brooks and Megat Johari, 2001)

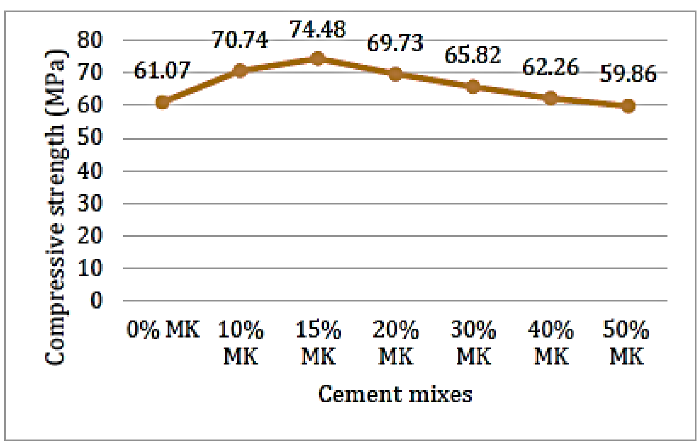


Figure 3 Compressive strength of concrete containing MK (Shehab El-Din et al., 2017)

According to research by (Sharaky et al., 2021), the compressive strength of concrete increased as the amount of MK replacement increased. It was observed that the compressive strength for MK0, MK10, MK15, MK20, MK30, MK40 and MK50 are 49.85 MPa, 58.15 MPa, 63.06 MPa, 55.87 MPa, 50.25 MPa, 46.22 MPa and 41.13 MPa respectively. A research on the strength and durability aspects of calcined kaolin-blended Portland cement has been performed (Vu et al., 2001). For this work, 10%, 15%, 20%, 25% and 30% of Metakaolin used as replacement of cement. It was found that compressive strength of concrete contains MK higher than control mix. The compressive strength of MK10, MK15, MK20 and MK30 are 25.19 MPa, 26.24 MPa, 25.42 MPa and 22.48 MPa respectively. Thus, MK can improve the strength of concrete since MK is a highly reactive material. However, compressive strength decrease with increase in MK content in concrete containing glass powder and increase with prolong curing period (Samson et al., 2016). Glass powder concrete cubes made with (5-20) % MK and cured for 56 and 90 days, achieved the 28 days target strength of 25 N/mm^2. The optimum replacement level was observed at G10%M15% cured for 90 days.

Table 1 summarizes the compressive strength with percentage improvement from previous studies. As shown in Table 1, the compressive strength of concrete contains MK has higher compressive strength than control mix concrete with percentage of improvement in range of 0.8% to 78.2%. It can be seen that highest compressive strength of concrete when the MK replacement is between range 10% to 20%. It is because MK is a highly reactive material. The replacement of cement with MK in concrete, results in the reduction of tri-calcium silicates (C3S) which is a main strength contributing compound. The fineness of MK is lesser than OPC and consequently cannot hydrate as quickly as cement. It also may be due to the effect of utilization of MK, which may reduce the permeability or porosity of the concrete.

Table 1 Summarization of compressive strength of concrete contains MK from previous studies

Author, year	Control mix (MPa)	Metakaolin content (MPa) with percentage improvement						
		5%	10%	15%	20%	30%	40%	50%
Brooks and Megat Johari, 2001	87	91.5 (+5.5%)	104 (+19.5%)	103.5 (+19.0%)	-	-	-	-
Shehab El-Din et al., 2017	61	-	70.74 (+16.0%)	74.48 (+22.6%)	69.73 (+14.3%)	65.82 (+7.9%)	62.26 (+2.1%)	59.86 (-1.9%)
Sharaky et al., 2021	49.85	-	58.15 (+16.6%)	63.06 (+26.5%)	55.87 (+12.1%)	50.25 (+0.8%)	46.22 (-7.3%)	41.13 (-17.5%)
Vu et al., 2001	23.68	-	25.19 (+6.4%)	26.24 (+10.8%)	25.42 (+7.3%)	22.48 (-5.1%)	-	-
Dadsetan and Bai, 2017	50.5	-	85 (+68.3%)	-	90 (+78.2%)	-	-	-

3.2 Effects of POFA on compressive strength of concrete

POFA is an agro-waste product derived from the palm oil industry's biomass energy generation using palm oil leftovers (fibres, kernel shells, and empty fruit bunches) (Altwair et al., 2012). When utilized as a supplementary cementitious material, POFA has been proven to be a good pozzolanic material that also improves the mechanical characteristics, microstructure, and durability performance of cement-based materials, especially at late stages of concrete maturation

(Tangchirapat et al., 2012). By eliminating some cement and substituting it with a less expensive substance, POFA can increase the performance of concrete while making concrete production more cost-effective. OPC were replace by original size of POFA (OP), median particle sizes 15.9µm POFA (MP) and 7.4µm size of POFA (SP) of 10%, 20%, 30% and 40% by weight of binder. According to (Tangchirapat et al., 2007), more times are required to set depending on the amounts of POFA replacing the cement and the degree of fineness of the POFA. Concrete that produced from cement and POFA with original size have lower compressive strength than traditional concrete samples, however concrete samples produced from cement and POFA with small particles have higher compressive strength than traditional concrete samples. Thus, Ground POFA (GPOFA), Ultrafine POFA (UPOFA), and Nano POFA are examples of finer POFA variations that can be obtained through grinding methods.

The use of palm oil fuel ash as a partial cement substitute ingredient contributed to the improvement of compressive strength for lightweight foamed concrete which contain 10%, 20% and 30% of POFA by 4.0 MPa, 4.8 MPa and 4.2 MPa respectively and it value is lower than the control concrete which is 6.9 MPa due to the slow pozzolanic activity of POFA (Alnahhal et al., 2021). However, the decreased compressive strength of POFA concrete is related to the coarser particle size of POFA, which resulted in a slow pozzolanic reaction rate (Tangchirapat and Jaturapitakkul, 2010). The higher quantity of POFA contribute to the lower value of concrete strength due to lower pozzolanic reactivity, high value of LOI, and the porous characteristic of POFA. Besides that, the compressive strength values of 77.5, 81.3, 85.9, and 79.8 MPa for OPC, POFA10, POFA20, and POFA30 on 28-day, using ground POFA replacement levels of 10%, 20%, and 30% in the manufacturing of HSC (Sata et al., 2004). When the ground POFA with the higher fineness that producing a high-strength concrete has been used, it was observed that compressive strength of OPC, GPA10, GPA20 and GPA30 was 58.5 MPa, 59.5 MPa, 60.9 MPa and 58.8 MPa (Tangchirapat et al., 2009). As a result, ground POFA with the highest fineness can be used as partial cement replacement material in producing high-strength concrete.

In addition, the research on high-strength green concrete with a high volume of ultrafine palm oil fuel ash shows the compressive strength of high strength green concrete containing UPOFA (OPC, POFA20, POFA40 and POFA60) are 91.4 MPa, 98.3 MPa, 104.2 MPa and 98.1 MPa respectively as shown in Figure 4 (Megat Johari et al., 2012). For the impact of ultrafine palm oil fuel ash's pozzolanic reactivity on the strength and durability of high-strength concrete, it shows that the present of UPOFA resulted in a decrease in early age of strength and the compressive strengths increase to 100.5 MPa, 105.2 MPa, 109.0 MPa, and 108.5 MPa respectively for high strength green concrete containing UPOFA (0%, 20%, 40% and 60%) after 90 days as shown in Figure 5 (Zeyad et al., 2017). Based on the research of high-strength green concrete containing high volume of UPOFA, it was found that the compressive strength of concrete contains UPOFA higher than control mix (Megat Johari et al., 2012). In the case of compressive strength, the inclusion of the POFA reduces early age strength of the HSGCs (high-strength green concrete) at 1, 3 and 7 days, but enhances the strength at 28 days for all HSGCs containing POFA, where the strength exceeding 95 MPa was achieved for all the POFA–HSGCs. The compressive strength of concrete contains of 20%, 40% and 60% of UPOFA were 98.3 MPa, 104.2 MPa and 98.1 MPa respectively.

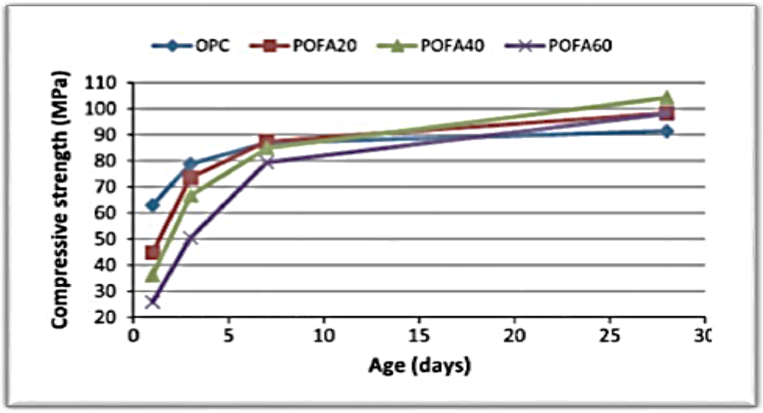


Figure 4 Compressive strength of high strength green concrete contain UPOFA (Megat Johari et al., 2012)

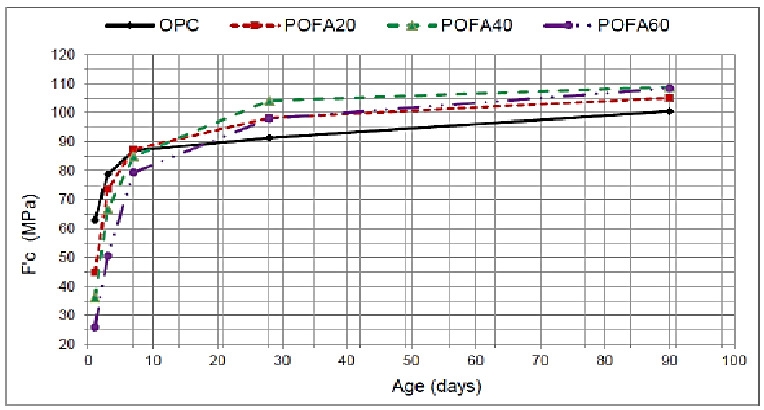


Figure 5 Compressive strength of HSG containing UPOFA (Zeyad et al., 2017)

In conclusion, Table 2 was the summarization of compressive strength with percentage improvement from previous studies. As shown in Table 2, the compressive strength of concrete contains raw POFA has lower compressive strength than control mix but concrete that contains GPOFA and UPOFA has higher compressive strength than control mix. This may be due to the fineness of POFA. The smaller the particle of POFA, it may increase the compressive strength of concrete. Raw POFA has lower compressive strength because POFA has slow pozzolanic reaction due to its particle fineness larger than OPC and high porosity. The raw POFA is absorbing more water than cement and cause the mixture to hydrate quickly. Thus, workability of concrete contains raw POFA lower than concrete without POFA. In order to increase the compressive strength of the concrete using POFA, smaller particle size of the POFA need to be used by grinding it or burning in order to obtain more fineness structure of POFA. By burning and grinding it more further, the silica content in POFA can be increased and thus will increased the compressive strength of the concrete. Compressive strength of concrete that contains POFA in the range between 4.0 MPa to 109.0 MPa with percentage improvement of 0.5% to 14% than control mix.

Author, year	Type of POFA	Control mix (MPa)	POFA content (MPa) with percentage improvement				
			10%	20%	30%	40%	60%
Alnahhal et al., 2021	Raw POFA	6.9	4 (-42.0%)	4.8 (-30.4%)	4.2 (-39.1%)	-	-
Osman et al., 2020	Raw POFA	27.62	25.22 (-8.7%)	24.84 (-10.1%)	19.36 (-29.9%)	-	-
Sata et al., 2004	GPOFA	77.5	81.3 (+4.9%)	85.9 (+10.8%)	79.8 (+3%)	-	-
Tangchirapat et al., 2018	GPOFA	58.5	59.5 (+1.7%)	60.9 (+4.1%)	58.8 (+0.5%)	-	-
Megat Johari et al., 2012	UPO FA	91.4	-	98.3 (+7.5 %)	-	104.2 (+14 %)	98.1 (+7.3 %)
Zeyad et al., 2017	UPO FA	100.5	-	105.2 (+4.7 %)	-	109 (+8.5 %)	108.5 (+8.0 %)

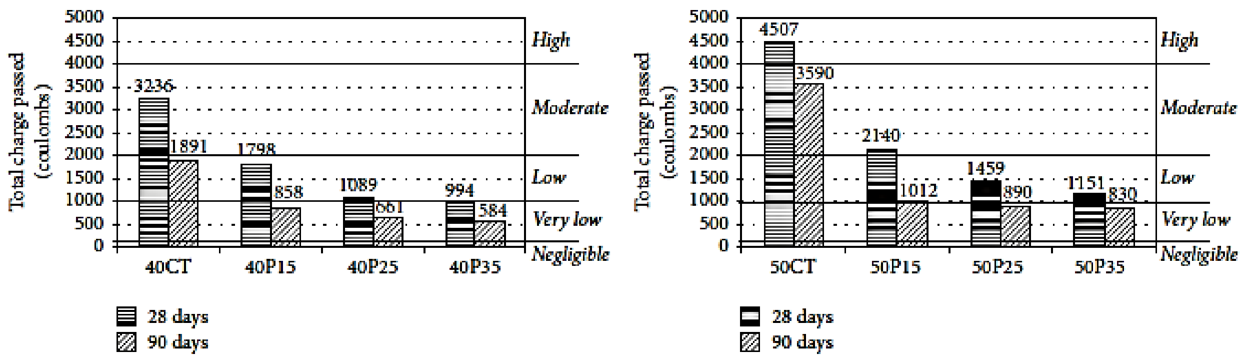
Table 2 Summarization of compressive strength of concrete contains POFA from previous studies

3.3 Effects of POFA and Metakaolin on temperature and tensile strength of concrete

Normally, the concrete properties are exposed to elevated temperature thus give effects on the structural stability and assessment of serviceability state of the structure. Higher residual weight loss of concrete samples has been observed when the samples are exposed to the high temperature (Abdul Awal and Shehu, 2015). The losses of concrete compressive strength are observed when the temperature achieved 800^{o}C. Meanwhile, the rate of decrease of tensile strength is greater when the temperature is above 400^{o}C (Anupama Krishna et al., 2019). The ternary blend that produced by combining 10% POFA and 10% MK by weight as a substitute to cement improved the compressive strength and microstructure of mortar exposed to elevated temperatures compared to plain OPC mortar (Usman et al., 2017). By using 5% of POFA replacement in concrete through powder technique, the optimum percentage of both compressive and splitting tensile strength is adopted (Sidek et al., 2018). However, tensile strength and modulus of elasticity decreased at elevated temperatures compared with ambient temperature (Paul et al., 2020). In term of the combination of different steel fiber proportions and polypropylene in the presence of Metakaolin, the good percentage of cement replacement with MK is 15% either with hybrid fiber volume fractions of 0.25% or 0.5% (Shehab El-Din et al., 2017). Due to the behaviour of low tensile strength and brittle nature, concrete does not resist any direct tension. Thus, the higher tensile strength of concrete is required to determine the load at which concrete members may start to crack.

3.4 Effects of POFA on water bender ratio

As shown in Figure 6, the effects of water bender (W/B) ratios on the compressive strengths of the POFA concrete were similar to those of conventional concrete; which is, the compressive strength of POFA concrete increased as the water bender ratio was decreased (Sanawung et al., 2017). Besides, the slump test results of different concrete mixes show low slump values between 25 and 40 mm, and this is attributed to high loss on ignition of POFA. The slump value 25-40 mm for POFA based OPSC was lower than the slump value 50-75 mm of structural lightweight concrete because of the lower water cement ratio (Ul Islam et al., 2021). However, by reducing the water-binder ratio in the range of 0.5–0.6, the compressive strength is not significantly affected (Golizadeh and Namini, 2015).



(a) W/B = 0.40 (b) W/B = 0.40

Figure 6 Chloride ion penetration and the replacement of ground POFA in concrete for W/B ratios of 0.40 and 0.50 (Sanawung et al., 2017)

This means that the replacement of POFA was more effective to reduce the total passed charges compared to the increase in the compressive strength (Sanawung et al., 2017). Thus, the chloride ion penetration of concrete tended to decrease when the replacement of ground POFA in the concrete increased.

3.5 Cracking behavior of reinforced concrete beam affected by MK

POFA is an agro-waste product derived from the palm oil industry's biomass energy generation using palm oil leftovers (fibres, kernel shells, and empty fruit bunches) (Altwair et al., 2012). POFA has been proven as a good pozzolanic material when was utilized as a supplementary cementitious material, that also improves the mechanical characteristics, microstructure, and durability performance of cement-based materials, especially at late stages of concrete maturation (Tangchirapat et al., 2012). By eliminating some cement and substituting it with a less expensive substance, POFA can increase the performance of concrete that contributed to the more cost-effective concrete production. It takes longer to set depending on the amounts of POFA replacing the cement and the degree of fineness of the POFA (Tangchirapat et al., 2007).

The reinforced concrete beams strengthened with MK has a higher load carrying ability and the fewest cracks as shown in Figure 7 (Deepthi et al., 2014). When the percentage of MK is adjusted from 0% to 10%, the mechanical performances of concrete mixes improved by varying the replacement percentages of cement by MK. Beyond 10%, the mechanical strength of concrete mixes containing MK show a downward trend. The use of Nano MK has no effect on beam failure mode, and the crack spacing in Nano MK concrete is smaller than in conventional concrete (Ahmed et al., 2017). As shown in Figure 8, the cracking of reinforced concrete beam without the Nano Metakaolin is more than the reinforced concrete beam with Nano Metakaolin. Thus, the usage of Nano Metakaolin in the reinforced concrete beam can increase the structural performance. It is because the MK contributes to the lower heat of hydration and thermal shrinkage and increasing the water tightness. It also helps to improve the early strength and workability. Thus, the increasing of MK content decreased the slump and the requirement of SP increases. This is due to the increased surface area of MK which absorbs more SP to maintain the required workability.

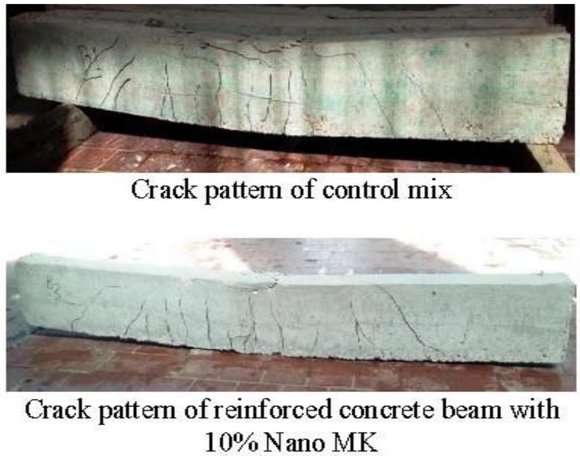


Figure 7 Crack pattern of reinforced concrete beam (Deepthi et al., 2014)

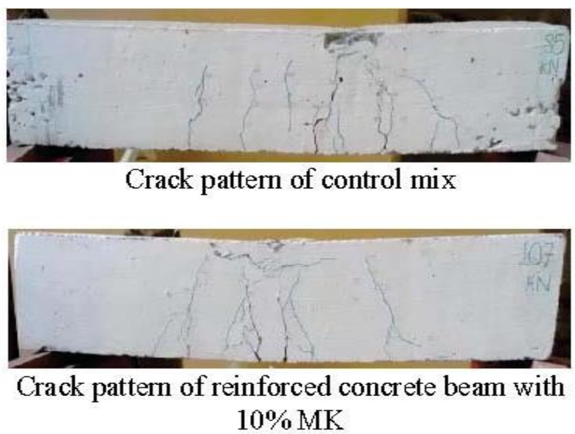


Figure 8 Crack pattern reinforced concrete beam (Ahmed et al., 2017)

3.6 Cracking behavior of reinforced concrete beam affected by POFA

The inclusion of POFA and ES powder has the potential to be examined as a cement alternative and it was observed that all beams show similar shear-flexure failure as shown in Figure 9. However, FC-POFA-ES has a higher number of cracks (Rahman et al., 2019). When the applied force was 6.0 kN, the control beam experienced early cracks in the middle part of the section with a size of 50 mm. Then, many cracks were discovered within the flexure zone. It is because the POFA has slow pozzolanic reaction due to higher particle fineness compared to that of OPC and also due to high porosity nature. It causes the concrete with POFA hydrate quickly and reduces the strength of concrete. The beam encountered flexure-shear failure at the overlay end when the ultimate load of 15.6 kN was reached.

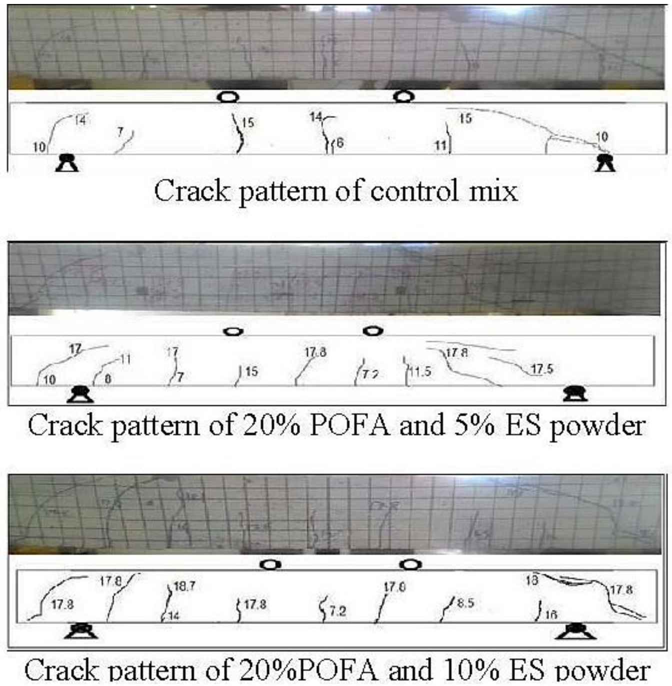


Figure 9 Crack patterns of FC-POFA-ES (Rahman et al., 2019)

3.7 Optimum content of MK

Meanwhile, it was found that the compressive strength increase from 0% to 30% of MK and beyond the 30% of MK, the compressive strength started to decrease when the use of steel fiber and MK has been adopted (Sharaky et al., 2021). It stated that the optimum content of MK is 15%. In term of the compressive, splitting tensile and flexural strength of concrete, the replacement rate of 10% MK was found to be higher than that of the control mix when using Metakaolin as cement replacement (Malagavelli et al., 2018). Nevertheless, the concrete with 10% MK concentration had enough compressive strength (Tawfik et al., 2019). Moreover, by replacing 10% of the cement in Hybrid concrete with 10% MK, increase the compressive strength (Mahyuddin et al., 2016). For the inclusion of MK in a range of 10% to 15% contribute to the higher compressive strength of concrete at both early and later curing ages, with 10 and 15% MK substitution giving compressive strength values greater than the control at 28 and 60 days, as shown in Figure 10 (Siamed et al., 2012). It was concluded that MK can be used as partial cement replacement because it can improve the strength of the concrete.

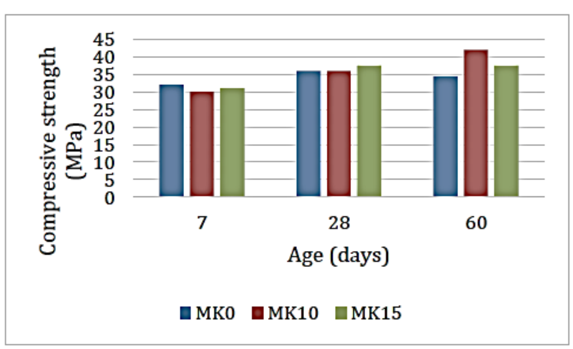


Figure 10 The compressive strength of concrete that contains MK. Source (Siamed et al., 2012)

MK replacement was performed in both normal and unfavorable conditions. Another research (Brooks and Megat Johari, 2001) shows that an increasing of compressive strength as the percentage of MK increase to 10%. As shown in Figure 9, the higher compressive strength when incorporating 10% of MK and it started to decrease when the percentage of MK was beyond the 10%. Moreover, the use of MK instead of cement improved the resistance of concrete to sulphate attack (Siddique and Klaus, 2009). Thus, the increase in the MK content as cement replacement results the sulfate resistance of concrete increase. It was observed that sulfate resistance was found to be excellent in concrete having 10% and 15% MK replacements.

In conclusion, the Table 3 is the summarization of optimum content of MK. From the Table 3, the optimum content of MK content is between 10% to 15% as partial cement replacement in order to get high strength of concrete due to MK is a highly reactive material. The replacement of cement with MK in concrete, results in the reduction of tri-calcium silicates (C3S) which is a main strength contributing compound. The fineness of MK is lesser than OPC and consequently cannot hydrate as quickly as cement. It also may be due to the effect of utilization of MK that can reduce the permeability or porosity of the concrete.

Table 3 Summarization of optimum content of MK from previous studies

Author, year	Optimum Content
Brooks and Megat Johari, 2001	10%
Shehab El-Din et al., 2017	10%-15%
Sharaky et al., 2021	15%
Malagavelli et al., 2018	10%
Tawfik et al., 2019	10%-20%
Mahyuddin et al., 2016	10%
Siamed et al., 2012	10%-15%
Vu et al., 2001	15%
Siddique and Klaus, 2009	10%-15%
Dadsetan and Bai, 2017	10%-20%

3.8 Optimum content of POFA

Hamada et al., (2018) conducted a research on the use of POFA in concrete and found out that by adding the 10–20 % of POFA improves the compressive, flexural, and tensile strength. Besides that, Muthusamy et al., (2015) found out the optimum content of POFA is 20% and it was the best 28-day compressive strength value. Meanwhile, Islam et al., (2016) reported that the optimum content of POFA is 10%. However, replacing cement with POFA may have the opposite effect on concrete strength, especially if the POFA proportions are too high when the structure is subjected to earthquakes.

Other than that, through the degree of water impermeability and strength of concrete that contain GPOFA, it was discovered that the compressive strengths of concretes containing 20% GPOFA were higher than the compressive strengths of OPC concrete (Chindaprasirt et al., 2007). GPOFA can be employed as a pozzolanic material in concrete to obtain appropriate impermeability and strength for concrete samples. Besides that, according to other research (Hamada et al., 2019) in making the lightweight aggregate concrete, the researcher employed POFA with nano particle sizes varying from 0% to 30%. The results showed that by replacing the cement with NPOFA, the workability, compressive strength may increase, meanwhile the UPV on a regular basis reducing the CO2 emissions into the atmosphere by up to 30%. Besides that, the high strength of concrete allows the substitution of UPOFA for up to 60% of OPC, with the resulting concretes performing better in terms of strength and transport characteristics compared to that of control mix (HSC-OPC) (Megat Johari et al., 2013). Meanwhile, the utilization of ground POFA (GPOFA) to replace cement (partially by 10, 20, 30, and 40%) and found that the effect of POFA on concrete mixtures and cement paste increases as the fineness of the POFA increases (Kroehong et al., 2011). Besides that, concrete with up to 30% UPOFA and NPOFA can have high compressive strengths of 90 MPa after 28 days and 112 MPa after 180 days (Hamada et al., 2021). As a result, the smaller the particle of POFA caused the better the performance of the concrete.

Moreover, by adding up to 20% POFA to concrete mixture leads to a more refined compressive strength than the control concrete at various curing ages (Sata et al., 2007). As shown in Figure 11, concrete that contain 10% to 20% of POFA shows the increasing trends but the value drop when the utilization of POFA beyond 20%. However, according to other research on the utilization of POFA and EPS, the optimum content of POFA is from 10% to 20% (Osman et al., 2020). Thus it is proved that the optimum POFA content that can produce high strength concrete is in the range of 10% to 20%.

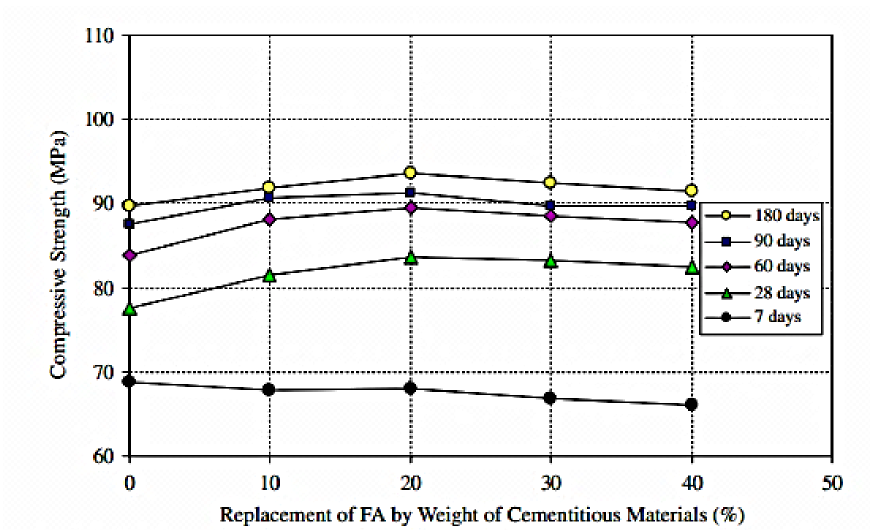


Figure 11 Compressive strength containing POFA (Sata et al., 2007)

In conclusion, Table 4 shows the summarization of optimum content of POFA. The optimum content of raw POFA, GPOFA, UPOFA and NPOFA were 10% to 20%, 30%, 60% and 30%. This may be due to the fineness of the POFA because the finer particle of the POFA contributes to the higher compressive strength of concrete. Raw POFA has lower compressive strength because POFA has slow pozzolanic reaction due to its particle fineness larger than OPC and high porosity. The raw POFA absorbing more water compared to that of cement and cause the mixture to quickly hydrate. Thus, workability of concrete contains raw POFA lower than concrete without POFA. In order to increase the compressive strength of the concrete using POFA, smaller particle size of the POFA need to be used by grinding or burning process in order to obtain more fineness structure of POFA. By burning and grinding process, the silica content in POFA can be increased and thus will increase the compressive strength of the concrete.

Table 4 Summarization of optimum content of POFA previous studies

Author, year	Type of POFA	Optimum Content
Hamada et al., 2018	Raw POFA	10%-20%
Muthusamy et al., 2015	GPOFA	20%
Islam et al., 2016	GPOFA	10%
Chindaprasirt et al., 2018	GPOFA	20%
Hamada et al., 2019	NPOFA	30%
Megat Johari et al., 2013	UPOFA	60%
Kroehong et al., 2011	GPOFA	20%
Sata et al., 2007	GPOFA	20%
Osman et al., 2020	Raw POFA	10%-20%
Hamada et al., 2021	UPOFA and NPOFA	30%

3.9 Chemical Composition of Concrete Mixture

For the impact of ultrafine palm oil fuel ash's pozzolanic reactivity, Brunauer, Emmett and Teller (BET) method using nitrogen gas absorption is one of the commonly used methods to measure the specific surface area of fine particles like, POFA and cement. Blaine surface area provides measurement of surface area using air permeability method (Zeyad et al., 2016). However, through chemical composition analysis, RHBA and POFA, according to ASTM C 618, can be said to be Class N pozzolan since the sum of SiO_2, Al_2O_3, and Fe_2O_3 are higher than or close to 70%, SO_3 are not higher than 4%, and LOI are close to 10% (Sata et al., 2007). In the lightweight aggregate concrete analysis, there was only a minimum amount of $Ca(OH)_2$ owing to its consumption in the pozzolanic reaction. When ultra-fine POFA was used in the place of ground POFA, the amount of $Ca(OH)_2$ has been further consumed as more amount of amorphous SiO2 was available to react with the $Ca(OH)_2$ (Hamada et al., 2019). The heat of hydration during concrete production may involve the chemical structure of POFA (Abdul Awal and Shehu, 2015) and also affects the compressive strength and workability. 43% to 71% of silicon dioxide (SiO2) is the main chemical composition ingredient of POFA, improve the pozzolanic reaction of high performance concrete (Zeyad et al, 2016).

4 Conclusions

From the study, the following conclusions can be drawn from the result of SLR on the work of the influence of POFA and MK on the concrete strength and reinforced concrete beam crack resistance:

1. The compressive strength of concrete that made up of MK concrete has a better compressive strength than control mix concrete, with improvements ranging from 0.8 to 78.2%. It can be shown that when the MK replacement is between 10% and 20%, the concrete has the highest compressive strength because MK is a highly reactive substance. When the cement is replaced with MK in concrete, the amount of tri-calcium silicates (C3S); a major strength contributor, is reduced. However, MK has a lower fineness than OPC, thus cannot hydrate as quickly as cement. It was also agreed that the use of MK reduces the permeability or porosity of concrete.

2. The compressive strength of concrete that made out of raw POFA was lower than control mix. It has a slow pozzolanic reaction than OPC because to its finer particle size and higher porosity. The raw POFA absorbs more water than cement, therefore the mixture hydrates quickly. As a result, the workability of concrete containing raw POFA is lower than that of concrete containing no POFA. In order to increase the compressive strength of concrete using POFA, the POFA particle size must be reduced by grinding or burning process, which results in a finer structure of POFA. The silica content of POFA can be raised by burning and grinding process, which improves the concrete's compressive strength. Concrete containing POFA has a compressive strength in the range of 4.0 MPa to 109.0 MPa, with a percentage improvement of 0.5 % to 14 % over the control mix.

3. It was identified that the inclusion of MK can decrease the crack on the surface of reinforced concrete beam while POFA can increase the cracks on the reinforced concrete beam due to the slow pozzolanic reaction. The beam that contains the MK and POFA experienced cracks within the flexure zone.

Conflict of interest

The authors declare no conflict of interest, financial or otherwise.

Acknowledgments

The financial support by the Fundamental Research Grant Scheme (Account number: 203/PAWAM/6071239) during the course of this work are gratefully acknowledge.

References

Abdul Awal A.S.M and Shehu I.A. (2015). Performance evaluation of concrete containing high volume palm oil fuel ash exposed to elevated temperature. Construction and Building Materials, 76, 214-220. http://dx.doi.org/10.1016/j.conbuildmat.2014.12.001

Ahmed M. A. (2017). Structural Performance of Reinforced Concrete Beams withNanoMeta-Kaolin in Shear. IOSR Journal of Mechanical and Civil Engineering, 14(02), 88-96. https://doi.org/10.9790/1684-1402048896

Altwair N. M., Megat Johari M. A. and Saiyid Hashim S. F. (2012). Flexural performance of green engineered cementitious composites containing high volume of palm oil fuel ash. Construction and Building Materials, 37, 518-525. https://doi.org/10.1016/j.conbuildmat.2012.08.003

Anupama Krishna D., Priyadarsini R. S. and Narayanan S. (2019) Effect of elevated temperatures on the mechanical properties of concrete. Structural Integrity Procedia, 14, 384-394

Anupama Krishna D., Priyadarsini R. S. and Narayanan S. (2021). High temperature effects on different grades of concrete. Sådhanå 46(31), 1-12, https://doi.org/10.1007/s12046-020-01536-6

Kitchenham B. and Stuart Charters S. (2007). Guidelines for performing Systematic Literature Reviews in Software Engineering. Technical Report EBSE 2007-001, Keele University and Durham University Joint Report.

Si-Ahmed M., Belakrouf A. and Kenai S. (2012). Influence of Metakaolin on the Performance of Mortars and Concretes. International Journal of Civil and Environmental Engineering, 6(11), 1010-1013.

Brooks J. J. and Megat Johari M. A. (2001). Effect of metakaolin on creep and shrinkage of concrete. Cement and Concrete Composites, 23(6), 495-502. https://doi.org/10.1016/S0958-9465(00)00095-0

Chindaprasirt P., Homwuttiwong S. and Jaturapitakkul C. (2007). Strength and water permeability of concrete containing palm oil fuel ash and rice husk-bark ash. Construction and Building Materials, 21(7), 1492-1499. https://doi.org/10.1016/j.conbuildmat.2006.06.015

Okoli C. (2015). A Guide to Conducting a Standalone Systematic Literature Review. Communications of the Association for Information Systems, 37(43), 879-910 DOI:10.17705/1CAIS.03743

Dadsetan S. and Bai J. (2017). Mechanical and microstructural properties of self-compacting concrete blended with metakaolin, ground granulated blast-furnace slag and fly ash. Construction and Building Materials, 146, 658-667. https://doi.org/10.1016/j.conbuildmat.2017.04.158

Dennison D. and Simon J. M. (2014). Effect of metakaolin on the structural behaviour of normal and steel fibre reinforced concrete. International Journal of Scientific and Engineering Research, 484, 2229-5518.

Demiral B. and Kelestemur O. (2010) Effect of elevated temperature on the mechanical properties of concrete produced with finely ground pumice and silica fume. Fire Safety Journal, 45(6-8), 385–91. https://doi.org/10.1016/j.firesaf.2010.08.002

Dewey A. and Drahota, A. (2016) Introduction to systematic reviews: online learning module Cochrane Training. https://training.cochrane.org/interactivelearning/module-1-introduction-conducting-systematic-reviews

Fantilli A. P., Mancinelli O. and Chiaia B. (2019). The carbon footprint of normal and high-strength concrete used in low-rise and high-rise buildings. Case Studies in Construction Materials, 11(e00296), 1-7. https://doi.org/10.1016/j.cscm.2019.e00296

Golizadeh H. and Namini S. B. (2015) Predicting the significant characteristics of concrete containing palm oil fuel ash. Journal of Construction in Developing Countries, 20(1), 85–98

Hamada H. M., Yahaya F., Muthusamy K. and Humada A. (2019). Effect of incorporation POFA in cement mortar and desired benefits: A review. IOP Conference Series: Earth and Environmental Science, 365(1),1-11. https://doi.org/10.1088/1755-1315/365/1/012060

Hamada H. M., Jokhio G. A., Yahaya F. M., Humada A., and Gul Y. (2018). The present state of the use of palm oil fuel ash (POFA) in concrete. Construction and Building Materials, 175, 26-40. https://doi.org/10.1016/j.conbuildmat.2018.03.227

Hamada H. M., Thomas B. S., Yahaya F. M., Muthusamy K., Yang J., Abdalla J. A. and Hawileh,R. A. (2021). Sustainable use of palm oil fuel ash as a supplementary cementitious material: A comprehensive review. Journal of Building Engineering, 40(102286), 1-14. https://doi.org/10.1016/j.jobe.2021.102286

Hamada H. M., Yahaya F. M., Muthusamy K., Jokhio G. A. and Humada A. M. (2019). Fresh and hardened properties of palm oil clinker lightweight aggregate concrete incorporating Nano-palm oil fuel ash. Construction and Building Materials, 214, 344-354. https://doi.org/10.1016/j.conbuildmat.2019.04.101

Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA (editors) (2020). Cochrane Handbook for Systematic Reviews of Interventions version 6.1 (updated September 2020). Cochrane, 2020. Available from www.training.cochrane.org/handbook

Jokhio G. A., Hamada H. M., Humada A. M., Gul Y. and Abu-Tair, A. (2020). Environmental benefits of incorporating palm oil fuel ash in cement concrete and cement mortar. E3S Web of Conferences, 158, 1-6. https://doi.org/10.1051/e3sconf/202015803005

Kroehong W., Sinsiri T., Jaturapitakkul C., and Chindaprasirt P. (2011). Effect of palm oil fuel ash fineness on the microstructure of blended cement paste. Construction and Building Materials, 25(11), 4095-4104. https://doi.org/10.1016/j.conbuildmat.2011.04.062

Lv P., Wang X., Liu Z., Yu J. and Liu, M. (2017). Porosity- and reliability-based evaluation of concrete-face rock dam compaction quality. Automation in Construction, 81, 196–209.

Malagavelli V., Angadi S. and Prasad J. S. R. and Joshi S. (2019). Influence of Metakaolin in Concrete as partial replacement of cement. International Journal of Civil Engineering and Technology, 9(7), 105-111.

Noyes J. and Lewin S. Chapter 5: Extracting qualitative evidence. In: Noyes J, Booth A, Hannes K, Harden A, Harris J, Lewin S, Lockwood C (editors) (2011). Supplementary Guidance for Inclusion of Qualitative Research in Cochrane Systematic Reviews of Interventions. Version 1 (updated August 2011). Cochrane Collaboration Qualitative Methods Group, 2011. Available from URL http://cqrmg.cochrane.org/supplemental-handbookguidance

Matar P. and Assaad J. J. (2019) Concurrent effects of recycled aggregates and polypropylene fibers on workability and key strength properties of self-consolidating concrete. Construction and Building Materials, 199, 492-500. https://doi.org/10.1016/j.conbuildmat.2018.12.091

Megat Johari M. A., Zeyad A. M., Muhamad Bunnori N. and Ariffin K. S. (2012). Engineering and transport properties of high-strength green concrete containing high volume of ultrafine palm oil fuel ash. Construction and Building Materials, 30, 281-288. https://doi.org/10.1016/j.conbuildmat.2011.12.007

Mohd Sam A. R. (2017) Konkrit. Edisi Pert. Edited by A.R.M. Sam. Johor Bahru:Penerbit UTM press.

Momeen M., Islam U., Mo K. H. and Alengaram U. J. (2016). Durability properties of sustainable concrete containing high volume palm oil waste materials. Journal of Cleaner Production, 137, 167-177. https://doi.org/10.1016/j.jclepro.2016.07.061

Muthusamy K. and Zamri N. A. (2015). Mechanical properties of oil palm shell lightweight aggregate concrete containing palm oil fuel ash as partial cement replacement. KSCE Journal of Civil Engineering, 00(0000), 1-9. https://doi.org/10.1007/s12205-015-1104-7

Orouji M., Zahrai S. M. and Najaf E. (2021) Effect of glass powder & polypropylene fibers on compressive and flexural strengths, toughness and ductility of concrete: An environmental approach. Structures, 33, 4616-4628. https://doi.org/10.1016/j.istruc.2021.07.048

Osman M. H., Adnan S. H., binti Mazlin N. I. and Wan Jusoh W. A. (2020). Properties of concrete containing palm oil fuel ash and expanded polystyrene beads. International Journal of Integrated Engineering, 12(9), 78-86. https://doi.org/10.30880/ijie.2020.12.09.010

Paul S., Rashid M. H. and Rahman M. A. (2020). Effect of elevated temperature on residual strength of self-compacted concrete. Journal of Engineering Science, 11(2), 107-115, DOI: https://doi.org/10.3329/jes.v11i2.50902

Rahman A. F., Goh W. I. and Jhatial A. A. (2019). Flexural Study of Reinforced Foamed Concrete Beam Containing Palm Oil Fuel Ash (POFA) and Eggshell Powder (ESP) as Partial Cement Replacement. International Journal of Sustainable Construction Engineering Technology, 10(1), 93-100.

Ramli M. B. and Alonge O. R. (2016). Characterization of metakaolin and study on early age mechanical strength of hybrid cementitious composites. Construction and Building Materials, 121, 599-611. https://doi.org/10.1016/j.conbuildmat.2016.06.039

Samson D., Abdullahi M. and Abba-Gana M. (2016). Effect of metakaolin on compressive strength of concrete containing glass powder, International Journal of Research in Engineering and Technology, 05(12), 137-142

Sanawung W., Cheewaket T., Tangchirapat W. and Jaturapitakkul C. (2017) Influence of palm oil fuel ash and W/B ratios on compressive strength, water permeability, and chloride resistance of concrete, Advances in Materials Science and Engineering, 4927640, 1-8, https://doi.org/10.1155/2017/4927640

Sata V., Jaturapitakkul C. and Kiattikomol K. (2004). Utilization of palm oil fuel ash in high-strength concrete, Journal of Materials in Civil Engineering, 16(6), 623-628. https://doi.org/10.1061/(ASCE)0899-1561(2004)16:6(623)

Sata V., Jaturapitakkul C., and Kiattikomol K. (2007). Influence of pozzolan from various by-product materials on mechanical properties of high-strength concrete. Construction and Building Materials, 21(7), 1589-1598. https://doi.org/10.1016/j.conbuildmat.2005.09.011

Seyed Mehdi Z., Mohamad Hosein M. and Erfan N. (2016). Using AP2RC & P1RB micro-silica gels to improve concrete strength and study of resulting contamination. Advances in concrete construction, 4(3), 195-206. http://dx.doi.org/10.12989/acc.2016.4.3.195

Sharaky I. A., Ghoneim S. S. M., Abdel Aziz B. H. and Emara M. (2021). Experimental and theoretical study on the compressive strength of the high strength concrete incorporating steel fiber and metakaolin. Structures, 32(1), 57-67. https://doi.org/10.1016/j.istruc.2021.01.061

Shehab El-Din H. K., Eisa A. S., Abdel Aziz B. H. and Ibrahim A. (2017). Mechanical performance of high strength concrete made from high volume of Metakaolin and hybrid fibers. Construction and Building Materials, 140, 203-209. https://doi.org/10.1016/j.conbuildmat.2017.02.118

Sidek M. N. M., Hashim N. H., Rosseli S. R., Nor M. R. M., Ismail S., Saman H. M., Arshad M. F., Alisibramulisi A. and Zainudin F. (2020) Utilisation of palm oil fuel ash (POFA) as cement replacement by using powder and liquidation technique, AIP Conference Proceedings, 020069(1), 1-7. https://doi.org/10.1063/1.5062695

Siddique R. and Klaus J. (2009). Influence of metakaolin on the properties of mortar and concrete: A review. Applied Clay Science, 43(3-4), 392-400. https://doi.org/10.1016/j.clay.2008.11.007

Tangchirapat W. and 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. https://doi.org/10.1016/j.cemconcomp.2010.08.008

Tangchirapat W., Jaturapitakkul C. and Chindaprasirt P. (2009). Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete. Construction and Building Materials, 23(7), 2441-2646. https://doi.org/10.1016/j.conbuildmat.2009.01.008

Tangchirapat W., Saeting T., Jaturapitakkul C., Kiattikomol K., and Siripanichgorn A. (2007). Use of waste ash from palm oil industry in concrete. Waste Management, 27(1), 81-88. https://doi.org/10.1016/j.wasman.2005.12.014

Tangchirapat W., Saeting T., Jaturapitakkul C., Kiattikomol K. and Siripanichgorn A. (2007).Use of waste ash from palm oil industry in concrete. Waste Management, 27(1), 81-88. https://doi.org/10.1016/j.wasman.2005.12.014

Tawfik T. A., Zaki W., Metwally K. A. and Serag Faried A. (2019). Hybrid effect of nano silica and metakaolin properties of cement mortar. International Journal of Engineering Research and Technology, 8(03), 211-215. http://dx.doi.org/10.17577/IJERTV8IS030145

Ul Islam M. M., Johnson Alengaram U. and Jumaat M. Z. (2021). Fresh and hardened properties of palm oil fuel ash (POFA) based lightweight concrete from palm oil industrial wastes, Proceedings of International Conference on Planning, Architecture & Civil Engineering, 09 - 11 September 2021, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh

Usman J., Mohd Sam A. R. and Hussin M. W. (2017) Behaviour of palm oil fuel ash and metakaolin ternary blend cement mortar at elevated temperatures, Journal of Materials in Civil Engineering, 29(2), 1-9. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001722

Vu D. D., Stroeven P. and Bui V. B. (2001). Strength and durability aspects of calcined kaolin-blended Portland cement mortar and concrete. Cement and Concrete Composites, 23(6), 471-478. https://doi.org/10.1016/S0958-9465(00)00091-3

Zeyad A., Megat Johari M. A., Tayeh B. and Moruf Olalekan Y. (2016). Efficiency of treated and untreated palm oil fuel ash as a supplementary binder on engineering and fluid transport properties. Construction and Building Materials, 125, 1066-1079. https://doi.org/10.1016/j.conbuildmat.2016.08.065