Recent Trends in Civil Engineering and Built Environment Vol. 2 No. 1 (2021) 181–189
© Universiti Tun Hussein Onn Malaysia Publisher's Office

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN : 2773-5184

A Review: The Performance of Reinforced Concrete Beam Containing Palm Oil Fuel Ash and Metakaolin Subjected to Four-Point Bending Test

Triman Rakasiwi D.R.A.[1], **Ismail M.H.**[2,*]

[1,2]Department of Civil Engineering, Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussien Onn Malaysia, Parit Raja, Batu Pahat, Johor, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rtcebe.2021.02.01.020
Received 30 January 2021; Accepted 28 April 2021; Available online 30 June 2021

Abstract: Lack of raw materials has been the challenge facing the construction sector in recent days. It is vital to reduce the environmental impact of the development of construction products. The perfect approach to achieving sustainable growth in the concrete sector is the use of waste and by-product materials in a concrete mix of renewable resources. In this study, the conventional concrete mix design was modified using POFA and MK as cement substitute material to understand structural behavior and compressive strength. Different percentages of POFA and MK in concrete show positive results for strength and durability. The properties of POFA and MK had been reviewed, such as physical, chemical, and mechanical properties. Throughout the review, POFA and MK properties had shown that it was an excellent material to use as cement replacement material due to its pozzolanic properties.

Keywords: Concrete, Compressive Strength, Palm Oil Fuel Ash, Metakaolin, Cracking Pattern, Sustainable Concrete

1. Introduction

The optimal material saving condition in the structural design is to reduce the weight of the composition without compromising its reliability and serviceability [1]. As a result, there has been an interest among researchers in looking at possible ways to overcome this shortcoming by altering the mixture of materials used in concrete casting. The use of waste and by-product materials in a concrete mix of renewable resources is therefore the perfect solution to achieve sustainable growth for the concrete industry. In this review study, palm oil fuel ash and metakaolin as partial cement substitute materials were replaced in the concrete under review.

The use of industrial waste, such as POFA and metakaolin, is one of the ways in which sustainable concrete can be used to mitigate environmental pollution, minimise cement and act as a means of

**Corresponding author: mohdhanif@uthm.edu.my*
2021 UTHM Publisher. All right reserved.

producing conventional building materials. Substituting concrete materials with palm oil fuel ash and metakaolin will reduce building materials and make construction more sustainable. Cracking negatively affects structural performance, shear rigidity and bending, ductility, energy absorption capability [2].

Strengthened concrete beams are one of the most common structural components. Despite the large number of beams designed and constructed, in order to prevent cracking, it is essential to consider the shear resistance in the beam. Cracks in concrete beams appear near the support, such as walls or columns, due to increased shear stress. Such fractures are also called shear cracks and are angled at 45 degrees horizontally. Such cracks in beams can be reduced by providing additional shear supports near the pillar where shear stress is highest. This is the key reason why there has been a rapid increase in interest among engineering communities over the last few years in understanding the response of reinforced concrete structures to materials. In response, it encourages researchers to focus their studies on the use of waste and by-product materials in future building materials. The crack width can be determined by the crack spacing of the beams. Reinforced concrete beams under constant load show a steady increase in strain and curvature over time due to creeping and concrete shrinkage. This increase in deformation leads to an increase in crack diameter (and beam deflection) and must be considered as likely to result in harmful actions over the service life of the building. The aim of this study is to review the performance of a reinforced concrete beam containing palm oil ash and metakaolin as partial cement substitute materials by doing some research based on articles and journals.

2. Materials and Methods Review

The selection of materials for construction work is essential in order to ensure that all structural buildings are safe to use and strong enough to stand. The material used by previous researchers were reviewed and compared.

2.1 Design Mix

The quality of the concrete production depends on the design of the concrete mix as well as on the correct mixing ratio. The mixing ratios used among researchers. The ratio of the mixture and the contents of the concrete mixture containing POFA and Mk are shown in Table 1 and Table 2.

Table 1: POFA concrete mix design used by researchers.

Reference	Percentage of materials (%)		Content (kg/m^3)					
	OPC	POFA	OPC	POFA	Water	Fine	Coarse	SP
[3]	100	0	437.78	0	197	643.68	1104.36	-
	90	10	394	43.78	197	643.68	1104.36	-
	80	20	350.22	87.56	197	643.68	1104.36	-
[4]	100	0	450	0	135	783.45	1146.23	0.9
	95	10	405	45	135	783.45	1146.23	0.9
	90	20	360	90	135	783.45	1146.23	0.9
[5]	100	0	The concrete mix used is M30 with a w/b of 0.45.					
	90	10						
	80	20						
	80	20						

Table 2: MK concrete mix design used by researchers.

Reference	Percentage of materials (%)		Content (kg/m^3)					
	OPC	MK	OPC	MK	Water	Fine	Coarse	SP
[6]	100	0	533.00	0	160	677	1201	2.13
	95	5	506.67	26.67	160	666	1182	2.93
	90	10	480	53.33	160	655	1163	3.47
[7]	100	0	437.78	0	197	643.68	1104.36	-
	95	5	415.89	21.89	197	643.68	1104.36	-

	90	10	394	43.78	197	643.68	1104.36	-
	100	0	420	0	189	644	1146	-
[8]	95	5	411.6	8.4	189	644	1146	-
	94	6	407.4	12.6	189	644	1146	-
	100	0	400	0	200	935	765	-
[9]	90	10	360	40	200	935	765	-
	85	15	340	40	200	935	765	-
	100	0	380	0	171	557	456	0.1
[10]	95	5	361	19	171	557	456	0.25
	90	10	342	38	171	557	456	0.4

2.2 Beam Specimen

Three specimens of beam were reviewed in this study. Three rectangular segment beams with a dimension of 200 × 500 × 2750 mm as specimen BS, 300 × 150 × 2240 mm as specimen C0, and 250 × 300 × 3200 mm as specimen B1.

2.3 Steel Reinforcement Rebar

The researchers' reinforcement bar detail is shown in Table 3, and the detailing of the reinforced concrete beam is shown in Figure 1, Figure 2 and Figure 3.

Table 3: Steel Reinforcement Detail

Reference	Bottom Bars (mm)	Top Bars (mm)	Stirrup (mm)	Stirrup Spacing (mm)
[11]	32	10	10	345@200
[12]	14	10	8	100
[13]	16	10	8	100

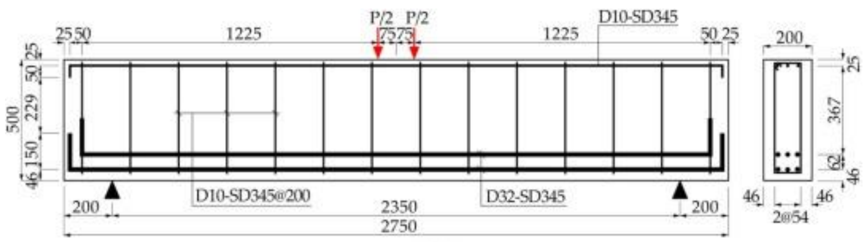

Figure 1: Detailing of reinforced concrete beam BS [11]

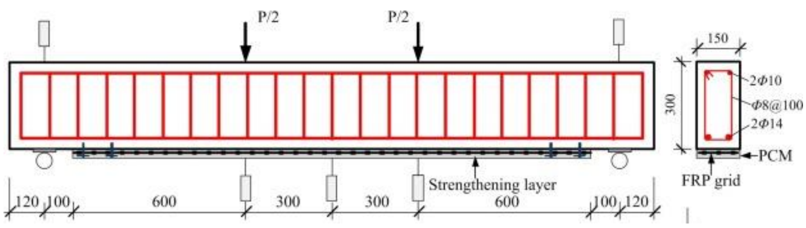

Figure 2: Detailing of reinforced concrete beam C0 [12]

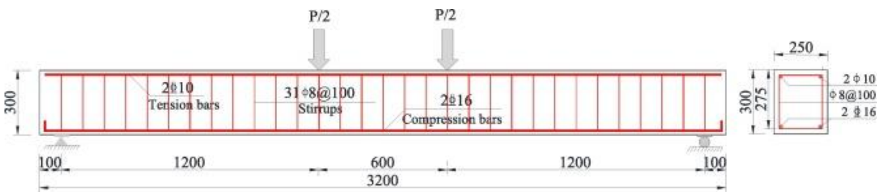

Figure 3: Detailing of reinforced concrete beam B1 [13]

3. Results and Discussion

The result and analysis were discussed on the basis of laboratory test carried out by previous research. Various types of articles have been selected for the crack pattern behavior of beams using palm oil ash and metakaolin as partial cement substitutes.

3.1 Tensile Test

The tensile strength of the concrete is one of the primary and vital properties that has an extraordinary impact on the degree and scale of cracking in the structures. Moreover, because of its porous existence, the concrete is under strain. Subsequently, direct tension does not depend on opposing it. The tensile strength graph for POFA and MK is shown in Figure 4 and Figure 5.

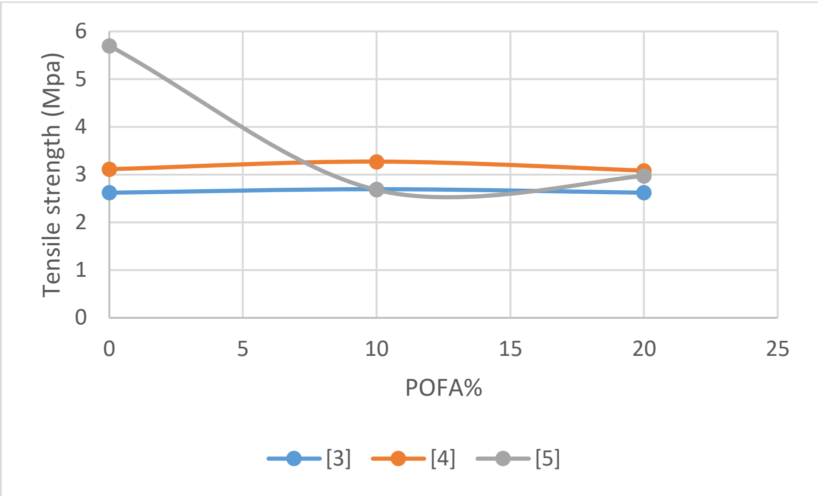

Figure 4: Graph of Tensile strength for POFA

Based on Figure 4, the concrete studies were conducted using 10% and 20% POFA for partial cement replacement. The result of the tensile strength showed that the inclusion of POFA in concrete resulted in a loss of strength. Experimental studies conducted by [4] and [3] show that the strength is increased with 10% POFA substitution, but the strength is slightly decreased when 20% POFA has been added. 10 per cent of POFA was found to have higher tensile strength than control, suggesting that 10 per cent of POFA is optimal for replacement. On the other hand,[5] show that the strength was the highest when no POFA was added.

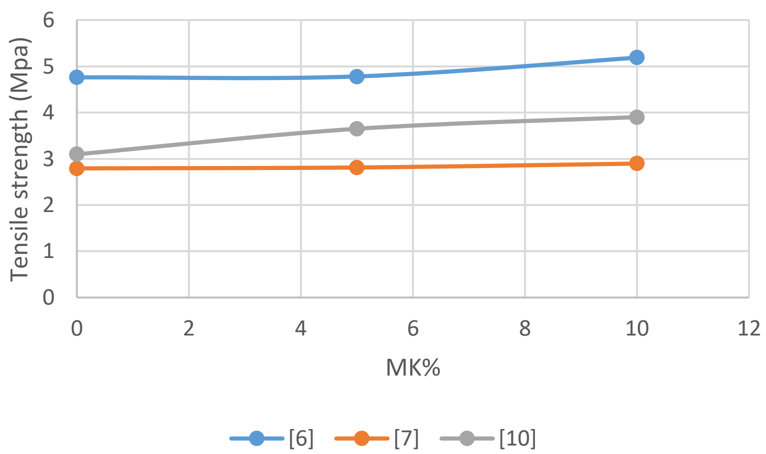

Figure 5: Graph of Tensile strength for MK

Results for tensile strength of 5 per cent and 10 per cent of metakaolin are shown in Figure 5. The result of the tensile strength showed that the inclusion of metakaolin in concrete resulted in an increase in strength. Out of the results, the tensile strength was the highest at 10% of metakaolin.

3.2 Compressive Test

Compressive strength is the most critical physical property that concrete possesses. The demand for water is higher when POFA is used in concrete. Various grades of strength have been reported by different researchers, depending on the fineness of the POFA and the amount of cement replacement. The higher amount of POFA used to replace cement in concrete will reduce its compressive strength [14]. The result of compressive strength for POFA and MK is shown in Table 4 and Table 5.

Table 4: Compressive strength result for POFA

Reference	POFA%	Compressive Strength (MPa) 7 days	28 days
	0	28.07	36.89
[3]	10	29.41	35.63
	20	27.71	32.70
	0	33.89	40.23
[4]	10	37.1	43.08
	20	31.68	39.55
	0	28.07	36.89
[5]	10	28.89	33.33
	20	29.79	36.44

Table 4 shows that the compressive strength of the concrete improved with age but decreased with an improvement in the substitution of POFA. The increased compressive strength of the concrete can be explained by three factors: the hydration response, the filling effect and the pozzolanic reaction.

Table 5: Compressive strength result for MK

Reference	MK%	Compressive Strength (MPa) 7 days	28 days
[6]	0	78.23	91.87
	5	78.74	95.60
	10	79.85	98.81
[7]	0	28.74	37.04
	5	32.07	38.22
	10	38.07	43.70
[9]	0	46	59
	10	50	67
	15	46.8	64.6

According to Table 5, the compressive strength of the concrete improved with age by increasing the substitution of metakaolin. In general, the substituted concrete had higher compressive strengths at different ages and up to 28 days when compared to the control concrete. The key factors affecting the contribution of MK to the intensity are the filling effect, the dilution effect and the pozzolanic reaction of MK to CH.

Table 6: Compressive Strength Increment Comparison Between POFA and MK

Percentage of Material Replaced (%)	Increment (%)			
	POFA		MK	
	7 days	28 days	7 days	28 days
10	4.77	26.93	32.46	52.05
	9.47	27.12	2.07	26.31
	2.92	18.74	8.70	40.43
Average	5.72	24.26	14.41	39.60

According to Table 6, the compressive strength increment comparison between POFA and MK shows that with 10% replacement of MK, it produces higher increment than POFA in 7 days and 28 days. MK provides immediate strength and durability improvements in early stage compared to POFA. This is because the concrete's compressive strength improved with age but decreased with an improvement in the substitution of POFA. The result shows that MK provides higher increment than POFA it shows that 10% MK substitution is better than 10% POFA substitution in concrete.

3.3 Flexural Strength

It is the strength of a beam or slab to withstand a bending failure. Flexural strength is known as the 'Rupture Module' (MR) in MPa. Flexural testing may be defined as the ability of the beam to maintain the load. This test is the most critical parameter to consider when building a beam. The material properties and the results of the comparison test are shown in Table 6 and Table 7.

Table 7: Material Properties

Reference	Compressive Strength of Concrete (MPa)	Reinforcement Strength	
		Diameter (mm)	Yield Tensile Strength (MPa)
[11]	34.1	10	423
		32	389
[12]	37	10	483
		14	472
[13]	35.6	10	401.17
		16	538.16

Table 8: Comparison Test Results

Reference	Specimen	Flexural cracking load (kN)	Cracking load (kN)	Ultimate load (kN)
[11]	BS	140	210	690
[12]	C0	108.2	19	117.7
[13]	B1	85	26	95

Based on Table 8, it has been shown that the first flexural cracking loads of the specimens, C0 and B1, were lower than the BS specimen. It must have been taken into account because the compressive strength of the BS concrete specimen is lower than that of specimens C0 and B1. In addition, specimens C0 and B1 are lower in critical cracking load compared to specimen BS. In addition, compared to specimens C0 and B1, the ultimate load of the specimen BS is the highest.

3.4 Crack Pattern

Based on the [11] result, the specimen occurred in Shear-compression failure modes such that, in the final stage, the maximum shear cracks penetrated the entire segment of the specimen and crushed the concrete at the shear yield point. The entire process of breakdown can be divided into three stages.

At the first point, as the load carried by the specimen approached 20% (140 kN) of the final load, flexicurity cracks were found at the bottom of the mid-span of the specimen. In the second stage, as the load increased to 30% (210 kN) of the final load for the specimens, Major diagonal cracks emerged and spread along the line connecting the loading point and the fulcrum side of the shear span. At the final level, when the specimens were filled to 690 kN, the major diagonal cracks exceeded the loading point and there was a cracking of the concrete. Figure 6 shows the crack patterns of the BS specimen.

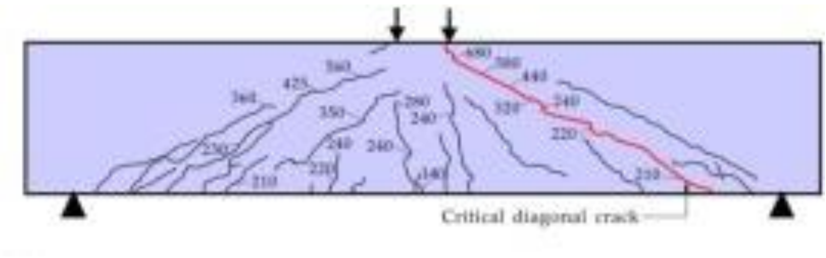

Figure 6: Crack patterns of specimen BS [11]

Next, on the basis of [12], the crack formation followed the typical crack pattern of the flexural members. The first noticeable crack was observed in the pure bending range when the applied load increased to 18,83 kN. Subsequently, some cracks were formed in the shear span as the applied load increased to approximately 35,31 kN and eventually extended to the load position. The crack width increased with the load applied prior to the collapse of the beam. Typical crack patterns of the C0 beam at the end of the test are shown in Figure 7.

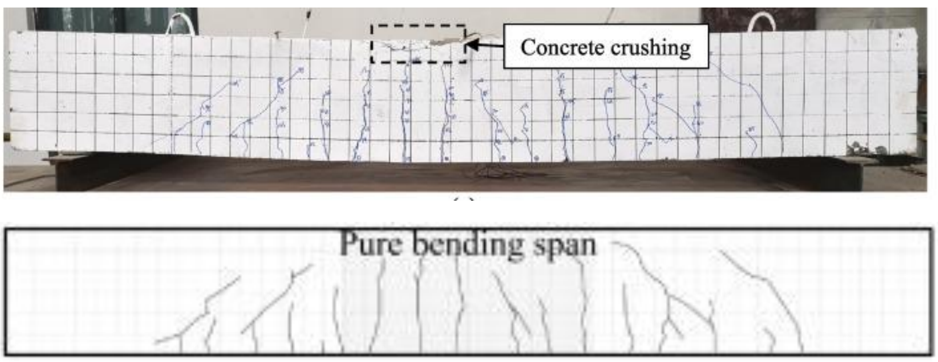

Figure 7: Crack patterns of specimen C0 [12]

Based on [13], the mid-span beam deflection increases linearly with the load at the initial loading point. As the load was applied to 26 kN, the first crack was observed in the pure bending section and the load-deflection curve was rotated, which meant that the deformation began to accelerate. As the load began to rise, new cracks gradually emerged, and the existing cracks continued to expand and widen. Most of them were vertical fractures between the loading points, others were located in the shearing period, where the bending moment was greater, and a few cracks were bent into the web of the beam.

Based on [13], as the load crossed 85 kN, the tension bar at the mid-span produced a maximum crack width of around 2.2 mm and the load-deflection curve revealed a major turning point. After that, crack depth, strain and deflection quickly increased, but new cracks seldom existed. At a load of 94 kN, weaving and crushing of compressed concrete were found near the loading point inside the pure bending section, signalling the final condition's arrival. The compressive strain of concrete at the mid-span was 3389 μш, the tensile strain of the steel bar was 6504 μш, and the maximum crack diameter was around 3.7 mm. Figure 8 display the crack patterns of the specimen B1.

Figure 8: Crack patterns of specimen B1 [13]

4. Conclusion

Physical and chemical properties suggest that the engineering efficiency of POFA and MK functions as a cement substitute material. The optimum level of cement substitution was 10%. Higher substitution percentage resulted in lower compressive strength. Overloading has a significant effect on the fatigue failure of the beam, including the failure mode. The reduced particle size of POFA and MK may benefit from the grinding process. The longer the grinding time is, the better the output. It was observed that the mid-span deflection of the beams tends to increase as the number of cycles increases. The same pattern was observed in crack growth, where cracks spread upward continuously. Failure of all beams under fatigue loading with overload occurred beyond the mid-span. Overloading redistributes the pressure within the beams and increases the impact of shear stress.

Acknowledgement

This research was made possible by funding from research grant number ABC-XXXX provided by the Ministry of Higher Education, Malaysia. The authors would also like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] S. Seara-Paz, B. González-Fonteboa, F. Martínez-Abella, and J. Eiras-López, "Flexural performance of reinforced concrete beams made with recycled concrete coarse aggregate," Eng. Struct., vol. 156, pp. 32–45, 2018.

[2] Q. Zhang, M. Khattak, and A. Das, "Mitigating Reflective Cracking Through the Use of a Ductile Concrete Interlayer," 2019.

[3] V. M. Sooraj, "Effect of palm oil fuel ash (POFA) on strength properties of concrete," Int. J. Sci. Res. Publ., vol. 3, no. 6, pp. 1–7, 2013.

[4] V. S. Aiswarya, W. Beyoola, and V. N. Harsha, "Palm oil fuel ash as partial replacement of cement in concrete," *Int. J. Eng. Res. Technol.*, vol. 6, no. 3, pp. 544–546, 2017.

[5] L. Subhashini and A. Krishnamoorthi, "Experimental investigation on partial replacement of cement by palm oil fuel ash in concrete," *Int. J. Adv. Res. Trends Eng. Technol.*, vol. 3, no. 4, pp. 44–48, 2016.

[6] P. Dinakar, P. K. Sahoo, and G. Sriram, "Effect of metakaolin content on the properties of high strength concrete," *Int. J. Concr. Struct. Mater.*, vol. 7, no. 3, pp. 215–223, 2013.

[7] N. John, "Strength properties of metakaolin admixed concrete," *Int. J. Sci. Res. Publ.*, vol. 3, no. 6, pp. 1–7, 2013.

[8] Q. Li, H. Geng, Z. Shui, and Y. Huang, "Effect of metakaolin addition and seawater mixing on the properties and hydration of concrete," Appl. Clay Sci., vol. 115, pp. 51–60, 2015.

[9] A. A. Ramezanianpour and H. B. Jovein, “Influence of metakaolin as supplementary cementing material on strength and durability of concretes,” *Constr. Build. Mater.*, vol. 30, pp. 470–479, 2012.

[10] G. Asadollahfardi, P. MohsenZadeh, and S. F. Saghravani, “The effects of using metakaolin and micro-nanobubble water on concrete properties,” *J. Build. Eng.*, vol. 25, p. 100781, 2019.

[11] B. Wang, Z. Wang, K. Uji, J. Zhang, and R. Guo, “Experimental investigation on shear behavior of RC beams strengthened by CFRP grids and PCM,” in *Structures*, 2020, vol. 27, pp. 1994–2010.

[12] W. He, X. Wang, and Z. Wu, “Flexural behavior of RC beams strengthened with prestressed and non-prestressed BFRP grids,” *Compos. Struct.*, p. 112381, 2020.

[13] C.-Y. Zhou, Y.-N. Yu, and E.-L. Xie, “Strengthening RC beams using externally bonded CFRP sheets with end self-locking,” *Compos. Struct.*, vol. 241, p. 112070, 2020.

[14] E. Khankhaje *et al.*, “On blended cement and geopolymer concretes containing palm oil fuel ash,” *Mater. Des.*, vol. 89, pp. 385–398, 2016.