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A Review: Performance Of Reinforced Concrete Beam With Metakaolin And Palm Oil Fuel Ash Subjected To Three – Point Loading

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Abstract: In the modern era, the usage of reinforced concrete is growing especially in building construction, but the production produced carbon dioxide that impacted the environment and can be prevented by replacing some cement content with Metakaolin (MK) and Palm Oil Fuel Ash (POFA). In this systematic literature review, it will focus on the reviewing the compressive strength of concrete containing MK and POFA, the structural behavior of reinforced concrete beam containing MK and POFA, and also analyse and comparing mechanical properties of concrete containing MK and POFA. The systematic literature review was done by obtaining papers, journal, and also articles related to the title and then the data from previous researchers will be analysed to obtain some optimum value for related test and prediction of future test. The review found that MK will increase compressive strength of concrete up to 12% and the flexural strength will improve up to 4.5% while POFA reduce the mechanical properties of concrete when using 10% but improve when increasing the percentage up to 20%, aside from that, the papers for crack pattern of reinforced concrete beam containing both materials was hardly to be found, it was expected the crack pattern would be flexural shear failure and less critical cracks due to the improvement in mechanical properties. In overall, MK have higher potential to be cement replacement rather than POFA in terms of mechanical properties of concrete.

Keywords: Compressive Strength, Flexural Strength, Metakaolin, POFA

1. Introduction

As one part of the building construction, the properties of concrete in both physical and mechanical plays a big part in determining strength and durability of material affecting the characteristics of concrete in building structures such as beam. The concrete had been researched for years before to produce concrete that can improve sustainability and reduce production of carbon dioxide and that's how Metakaolin (MK) and Palm Oil Fuel Ash (POFA) got introduced to be cement replacement in

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cement mixture. The materials have been researched many years, both of them have been occasionally used in concrete and give positive results in improving mechanical properties of concrete [1].

Other than the mechanical properties of concrete, research on the behavior of structure made from the concrete mixed with MK and POFA should also be considered especially in crack pattern of beam. The crack pattern will be produced differently depending on the material used on the concrete. With the aim of carrying out an accurate structural design, some concrete parameters have to be considered such as tension stiffening, strength capacity or cracking behavior [2]. The cracking behavior of reinforced concrete will determine the concrete strength and its serviceability.

The aim of this research is to review compressive strength of concrete containing MK and POFA, review the structural behavior of reinforced concrete beam with specific materials subjected to three – point loading test especially in cracking, to analyse and compare and also to predict the actual result that will get when using the mixture of cement with both materials based on the reviews. The data was taken from previous study by using the systematic literature review method that related to the title. In that case, this study determines the potential of MK and POFA in contributing to the properties of the reinforced concrete focusing in compressive strength, flexural strength and structural behavior especially in cracking. By analysing and comparing the data from previous study, this research can proof the properties of the concrete and contribute to the preparation of the test related in the future.

2. Methodology

The accuracy in preparation of materials and specimen is essential to make sure that the tests will produce an accurate result. The design mix and specimens used by previous researchers were reviewed and compared.

2.1 Design mix

Table 1 and 2 show the design mix of concrete containing MK and POFA used by previous researcher. The replacement of cement is depending on the weight of cement that were used to produce the concrete.

Table 1: Design mix for concrete containing MK

Reference	Percentage of OPC (%)	Percentage of MK (%)
[3]	100	0
	95	5
	90	10
	85	15
	80	20
[4]	100	0
	95	5
	92.5	7.5
[5]	100	0
	95	5
	90	10
[6]	100	0
	95	5
	90	10
	85	15

Table 2: Design mix for concrete containing POFA

Reference	Percentage of OPC (%)	Percentage of POFA (%)
[7]	100	0
	90	10
	80	20
	70	30
	60	40
[8]	100	0
	90	10
[9]	100	0
	90	10
	20	20
	30	30
	40	40
[10]	0	0
	5	5
	7.5	10
	10	15
	12.5	12.5
	15	15
	17.5	17.5
[11]	100	0
	90	10
	70	30
	50	50

2.2 Beam Specimen

Three beam specimens reviewed in this research consist of conventional reinforced concrete beams with different dimensions. According to [12], the dimensions of the reinforced concrete beam used was 1200 mm × 100 mm × 200 mm with 12mm reinforcement bars diameter. On the other hand, [13] and [14] show that the reinforced concrete beams dimensions were 1700 mm × 150 mm × 250 mm with reinforcement bar size of 22 mm and 13 mm, respectively.

3. Results and Discussion

The results based on the tests done by previous researcher were gathered, compared and analysed to predict the potential of MK and POFA on the performance of reinforced concrete beams.

3.1 Compressive strength of concrete containing MK and POFA

Based on previous research, the value of the compressive strength of concrete containing MK varies depending on the percentage of MK used. Some researchers didn't have the value of compressive strength of concrete for 7 days and 90 days of curing age. Table 3 and 4 show the results of the compressive strength of concrete containing MK and POFA.

Table 3: Compressive strength of concrete containing MK

Reference	Compressive strength (N/mm^2)			
	Percentage of MK	7 days	28 days	90 days
[3]	0	28.74	37.04	-
	5	32.07	38.22	-
	10	38.07	43.7	-
	15	41.19	51.56	-
	20	38.96	45.49	-
[4]	0	-	42	-
	5	-	52	-
	7.5	-	53	-
[5]	0	-	44	46.2
	5	-	45	46.8
	10	-	46	48

According to [3], the compressive strength of concrete containing MK increased up to 43.32% when using 15% of MK. For the 28 days of curing age, [4] obtained the highest value which is 53N/mm^2 for replacing cement with MK by 7.5%. In the other hand, [3] obtain the highest value when replacing cement with 15% of MK which is 51.56N/mm^2 making an increment of 39.20%. [5] obtained the value of 46N/mm^2 while replacing cement with MK by 10% making the increment of 4.55%.

Table 4: Compressive strength of concrete containing POFA

Reference	Compressive Strength (N/mm^2)						
	Percentage of POFA (%)	7 days			28 days		
		W/C ratio			W/C ratio		
		0.50	0.55	0.60	0.50	0.55	0.60
[7]	0	22	19	18	31	29	27
	10	21	20	17	32	30	28
	20	21	19	16	33	29	27
	30	19	17	14	30	27	25
	40	17	15	14	27	26	23
[8]	0		-			42.37	
	10		-			36.37	
[9]	0		28.07			36.89	
	10		28.89			33.33	
	20		29.78			36.44	
	30		25.78			29.33	
	40		20			26.22	

For the compressive strength of concrete containing POFA, the concrete that were cured for 7 days have the highest value of 29.78 N/mm^2 from [9] with the replacement of cement with POFA of 20%. For the concrete that were cured for 28 days, it was seen that the value of compressive strength reduced for two of the researchers. Taking the consideration of general concrete with 0.5 water-cement ratio, the value of compressive strength increase to 33N/mm^2 for [7] at the replacement of cement with POFA by 20%. For the reduction of compressive strength value, [15] and [16] stated that the fineness of POFA will greatly affected the compressive strength of concrete where the fineness of POFA passing 45μm sieve will produce concrete with higher compressive strength.

3.2 Flexural study and crack pattern of reinforced concrete containing MK and POFA

The flexural strength of the concrete is different from each of the researchers and most of them used the four-point bending test to determine the flexural strength of the concrete. For the crack pattern, it was hardly any paper related to the crack pattern of reinforced concrete containing MK and POFA. Table 5 and 6 show the flexural strength of concrete containing both MK and POFA from previous researchers.

Table 5: Flexural strength of concrete containing MK

Reference	Percentage of MK (%)	Flexural Strength for 28 days (N/mm^2)	Percentage of changes of flexural strength (%)	
			Increment	Decrement
[3]	0	5.84	-	-
	5	6.12	4.79	-
	10	6.32	8.22	-
	15	6.73	15.24	-
	20	6.45	10.45	-
[4]	0	4.8	-	-
	5	4.9	2.08	-
	7.5	6.6	37.5	-
[6]	0	4.62	-	-
	5	4.75	2.81	-
	10	4.87	5.41	-
	15	4.81	4.11	-

From the Table 5, the concrete containing MK have the highest increment of flexural strength of 37.5% from [4] with 6.6 N/mm^2 at replacement of cement with MK by 7.5%. The results also show that there wasn't any decrement in the flexural strength meaning that Metakaolin (MK) contribute in the strength of the concrete making the flexural strength increase due to the reaction between MK properties and cement properties.

Table 6: Flexural strength of concrete containing POFA

Reference	Percentage of POFA (%)	Flexural Strength for 28 days (N/mm^2)	Percentage of changes of flexural strength of concrete (%)	
			Increment	Decrement
[9]	0	5.7	-	-
	10	5.75	0.88	-
	20	6.5	14.04	-
	30	6	5.26	-
	40	4.5	-	21.05
[10]	0	3.78	-	-
	5	3.23	-	14.55
	7.5	2.10	-	44.44
	10	3.23	-	14.55
	12.5	3.43	-	9.26
	15	4.23	11.90	-
	17.5	3.50	-	7.41
[11]	0	6.04	-	-
	10	5.99	-	0.83
	30	3.95	-	34.60
	50	2.11	-	65.07

For the concrete containing POFA, Table 6 shows that most of the results will undergo decrement where the highest value of decrement was 65.07% from [11] where the percentage of replacement of cement with POFA is 50%. [9] shows some increment in the flexural strength up to 14.04% with the replacement of cement with POFA at 20%. It can be seen that the optimum value that can be used to replace cement is around 15% to 20%.

For the crack pattern, the conventional reinforced concrete beam will be used as the benchmark where the arrangement and size of reinforcement bar will heavily affect the crack pattern produced on the beam. Table 7 shows the failure mode of reinforced concrete beam from previous researchers.

Table 7: Table of crack pattern of conventional reinforced concrete beam

Reference	Specimen Designation	Crack load (kN)	Ultimate load (kN)	Percentage of ultimate load (%)	Failure Mode
[12]	2ϕ12	60	83	72.29	Flexure-Shear
[13]	RC3_S56	185	200	92.5	Flexure-shear
[14]	DR3.3_0.84_0.15	70	80	87.5	Flexure-Shear

From Table 3.5, it can be seen that all the sample undergo failure mode of flexure-shear failure where one of the researcher observed that the failure produced critical cracks where the shear cracks produced near the support and many flexure-shear cracks produced along the beam showing the excessive bending on the beam.

3.3 Comparison between MK and POFA

The data from the previous researches contain a lot of information where the results dependant on many factors such as the compaction of the concrete and also the rate of reactions during the production of the concrete. Table 8 shows the increment of compressive strength of concrete containing the material while Figure 1 shows the average increment of compressive strength of concrete.

Table 8: Average increment of compressive strength of concrete containing MK and POFA

Parameters	Increment (%)						
	Percentage of Materials Replaced (%)	Reference	Metakaolin		Reference	POFA	
Compressive strength			7 days	28 days		7 days	28 days
	10	[3]	32.46	17.98	[7]	-4.55	3.23
		[4]	-	-	[8]	-	-14.16
		[5]	-	4.55	[9]	2.92	-9.65
Average increment			10.82	7.51		-0.54	-6.86
	20	[3]	35.56	22.81	[7]	-4.55	6.45
		[4]	-	-	[8]	-	-
		[5]	-	-	[9]	6.09	-1.22
Average increment			11.85	7.60		0.51	1.74

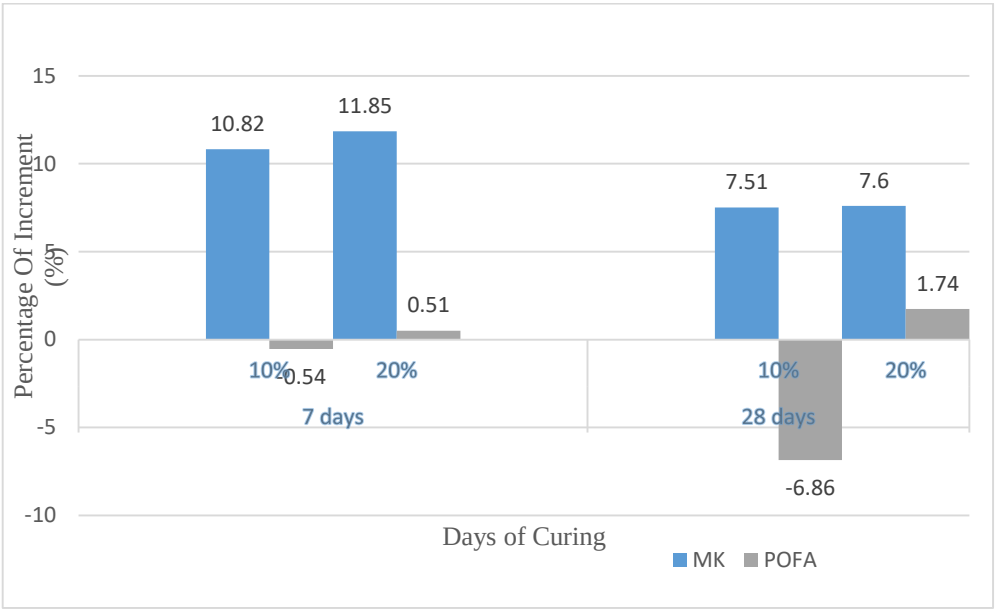

Figure 1: Average Increment of Compressive Strength of concrete containing MK and POFA

Based on the comparison of the compressive strength test from Table 8 and Figure 1, the value of compressive strength of concrete containing MK with optimum percentage of 20% is expected to have increment. For the concrete containing POFA, the compressive strength of concrete would decrease and increase around 0.5% when replacing cement by 10% and 20% of POFA respectively. For the concrete that have been cured 28 days, decreased in compressive strength by around 6% was seen.

Table 9: Percentage of average increment of flexural strength containing MK and POFA

Parameters	Percentage of Materials Replaced (%)	Increment (%)			
		Reference	Metakaolin	Reference	POFA
Flexural strength	10%	[3]	8.22	[9]	0.88
		[4]	-	[10]	-14.55
		[6]	5.41	[11]	-0.83
Average increment			4.54		-4.83
	20%	[3]	10.45	[9]	14.04
		[4]	-	[10]	-
		[6]	-	[11]	-
Average increment			3.48		4.68

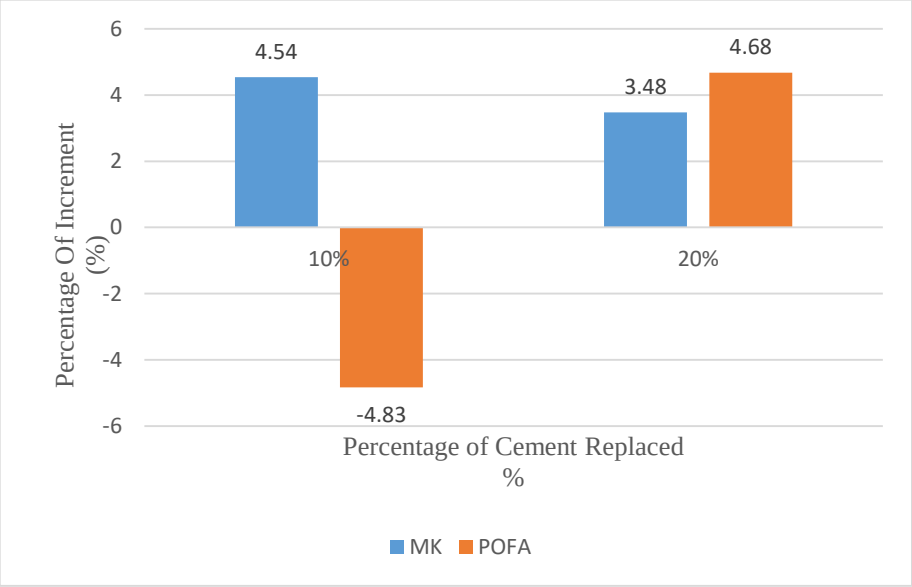

Figure 2: Percentage of increment of flexural strength of concrete containing MK and POFA

Based on Table 9 and Figure 2, the flexural strength of concrete will be dependent on the grade of concrete and for the reinforced concrete, the size of reinforcement bar will also play a big part. The MK would increase the flexural strength while POFA highly dependent on the fineness of particles of POFA. Table 3.7 and Figure 3.2 shows the average increment of flexural strength of concrete containing MK and POFA

For the crack pattern on the reinforced beam containing MK and POFA under three-point bending test, relating to the flexural strength that have been analysed, the crack pattern that will be produced on the reinforced concrete containing MK is flexural – shear failure and expected to be less width and less critical on both flexure and shear cracks. Reinforced concrete containing POFA in the other hand will be expected to produced more cracks that are critical for the beam due to its decrement of flexural strength.

4. Conclusion

For this review, the first objective is to review the structural behaviour of the concrete containing the specific materials that have been replaced by weight. In this review, the concrete containing MK can be seen that the compressive strength of 7 days and 28 days of curing have increment while replacing with POFA gives the increment at the early age of 7 days of curing and decrement at the age of 28 days.

Based on the second objective which is to review the structural behaviour of reinforced concrete beam containing the materials specifically in crack pattern comes into a halt when there's hardly any papers related to the title that used the material. While relating to the flexural strength test of the concrete containing specific material, the reinforced concrete containing the materials are expected to have flexure-shear failure in which less critical cracks will be produced.

Finally, the analysis and comparisons show that using MK can improve the concrete properties as well as improve the flexural strength of reinforced concrete. Meanwhile, the concrete containing POFA will be affected negatively especially in flexural strength. The analysis shows that the POFA have the ability to improve the concrete properties at the early age of curing but not at the late stages such as 28 days of curing due its fineness of the material.

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