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Effect of Water Binder Ratio on Compressive Strength of Concrete Produced with Palm Oil Fuel Ash

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Abstract

This study involved the prediction of compressive strength of concrete produced with different proportions of palm oil fuel ash (POFA) as partial replacement of concrete as a function of water binder ratio. Water binder ratios of 0.22, 0.25 and 0.27 were investigated at various POFA replacement of 7.5%, 10%, 12.5% and 15% and cement contents of 450kg/m^3, 550kg/m^3 and 650kg/m^3 for 28 days curing age. The results obtained from the experiment for each mix design were fitted into a linear regression model as a function of the water binder ratio. The results obtained from the linear regression model agreed with the experimental values. The correlation coefficients for all the POFA replacement percentages, including 0% POFA, were between 0.90 to 0.9999, except for 10% POFA replacement with cement contents of 550kg/m^3, which was 0.8512. However, the compressive strength of concrete decreased with an increase in the water binder ratio. Again, the compressive strengths were highest at a cement content of 650 kg/m^3. Hence the high agreement between the predicted and experimental data showed that the linear regression model has the capacity for prediction compressive strength of concrete at any given water binder ratio.

Keywords: *Mix design, POFA, Compressive Strength, Water Binder Ratio*

I. INTRODUCTION

Advancement in material technology and the need for high strength concrete has facilitated research on the exploitation of various agricultural wastes. The conversion of these wastes to structural materials is of immense benefit to not only the civil profession but also the management of the environment [1].

An investigation into pozzolan materials as partial replacement of cement for concrete has recorded remarkable achievement [2], [3], [4], [5], [6]. It has also been reported that the utilization of cementitious materials and wastes for concrete in structures will help in the reduction of greenhouse emissions [5]. Also, previous studies have shown that pozzolan materials like palm oil fuel ash have chemical components such as silica, ferrous oxide, aluminum oxide, calcium oxide, and many other metallic oxides, which are special properties required for making cement for structures [7], [8].

Various reports on the appropriate replacement ratio of pozzolan materials for cement have been documented. Thus, for palm oil fuel ash (POFA), 5% to 15% replacement ratio has been widely reported as the optimum values to obtain a high compressive strength of concrete [9], [10]. But besides the dose required for the performance of pozzolan concrete, the water binder ratio (W/B) is one of the most significant factors which controls the workability and strength of concrete. Ode *et al*. have demonstrated the efficacy of water binder ratio in improving or reducing the workability of the compressive strength of concrete, though this could impair negatively too, by reducing the compressive strength of concrete if the water binder ratio is excessive [11]. Ettu *et al*. applied a water binder ratio of 0.6 [12], while 0.5 of water binder ratio was used by Tonnayopas *et al*. [13]. They all reported a good compressive strength of concrete. Also, Oyejobi *et al*. using a 0.5 water binder ratio at 10% POFA, obtained concrete with compressive strength of 23.77 N/mm^2 after 28 days of curing [14]. In a similar study using 10% POFA replacement and reducing the water binder ratio to 0.3, Rani and Tejaanvesh obtained a high compressive strength concrete up to 66.7 N/mm^2 at the same 28 days curing. They equally observed that even when the POFA content was increased to 25%, the concrete compressive strength was still high up to 62.24 N/mm^2, compared to those produced using a relatively higher water binder ratio up to 0.5 and above [15]. The effect of water binder ratio on compressive strength of concrete produced using POFA was investigated at water binder ratios of 0.40, 0.45, and 0.50, which revealed that optimum compressive strength concrete was obtained at a water binder ratio of 0.40, indicating that the strength of concrete produced with pozzolanic materials is affected by excessive water binder ratio [16].

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However, it is imperative to forecast a possible strength of concrete at any given mixing parameter like water binder ratio. This would help reduce cost and wastages through obtaining pre-information on the possible outcome of what compressive strength of concrete, especially with pozzolan material, should be. Therefore, the objective of this study is to develop an appropriate water binder ratio require to obtain a desired compressive strength from partial replacement concrete. In achieving this, the linear regression model was used for the analysis.

II. MATERIALS AND METHODS

The following materials were used in carrying out the experimental analysis: binder, water, Portland Limestone Cement (P.L.C. Grade 42.5), Palm oil fuel ash, 212 microns sieve, 12mm coarse aggregate, 4.75mm fine aggregate, and AuraCast 200 chemical admixture.

A. Sample collection and Preparation

Empty palm bunches (palm husks) were obtained from the palm oil processing industry at Elele community, Ikwerre Local Government Area of River State, Nigeria. They were air-dried for about two weeks to remove moisture content. Thereafter, the dried empty palm bunches were burnt to ashes and then grinded to powered form. The grinded ashes were further dried in the oven-dried before being sieved through 212micron. The cement was lump-free and in compliance with America Concrete Institute (A.C.I.) for high strength concrete, and it is manufactured by Dangote Group of Company Plc. The coarse aggregate was crushed to a uniform size of 12mm coarse aggregate size, while the natural sand was collected from Umuechem River in Etche L.G.A. of Rivers State. The sand was then sieved to a maximum of 4.75m particle sizes.

B. Concrete Mix Design

The concrete mix design was performed according to our earlier work [17]. Thus, the dimensions of the cubes were 150mm x150mm x 150mm. The specimens were cast and properly vibrated using electric power vibrating table and then wrapped with cellophane for 48hours before removing them from the mold. The cubes were cured in a water curing tank for 28 days prior to testing. The various proportions of POFA, water binder ratios, fine and coarse aggregates, and water content at a specified cement content as shown in Tables I to III were prepared and investigated.

TABLE I
Concrete mix design at 450kg/m^3

W/B	0.22					0.25					0.27				
Parameter	0%	7.5%	10%	12.5%	15%	0%	7.5%	10%	12.5%	15%	0%	7.5%	10%	12.5%	15%
Cement (kg/m^3)	450	416.25	405	393.75	382.5	450	416.25	405	393.75	382.5	450	416.25	405	393.75	382.5
POFA (kg/m^3)	0	33.75	45	56.25	67.5	0	33.75	45	56.25	67.5	0	33.75	45	56.25	67.5
Water	99	99	99	99	99	112.5	112.5	112.5	112.5	112.5	121.5	121.5	121.5	121.5	121.5
Sp(kg/m^3)	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75
Fine (kg/m^3)	832	832	832	832	832	826	826	826	826	826	822	822	822	822	822
Coarse (kg/m^3)	1059	1059	1059	1059	1059	1051	1051	1051	1051	1051	1046	1046	1046	1046	1046

TABLE II
Concrete mix design at 550kg/m^3

W/B	0.22					0.25					0.27				
Parameter	0%	7.5%	10%	12.5%	15%	0%	7.5%	10%	12.5%	15%	0%	7.5%	10%	12.5%	15%
Cement (kg/m^3)	550	508.75	495	481.25	469.5	550	508.75	495	481.25	469.5	550	508.75	495	481.25	469.5
POFA (kg/m^3)	0	41.25	55	68.75	82.5	0	41.25	55	68.75	82.5	0	41.25	55	68.75	82.5
Water	121	121	121	121	121	138	138	138	138	138	148.5	148.5	148.5	148.5	148.5
Sp(kg/m^3)	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
Fine (kg/m^3)	778	778	778	778	778	758	758	758	758	758	749	749	749	749	749
Coarse (kg/m^3)	991	991	991	991	991	965	965	965	965	965	953	953	953	953	953

TABLE III
Concrete mix design at 650kg/m^3

W/B	0.22					0.25					0.27				
Parameter	0%	7.5%	10%	12.5%	15%	0%	7.5%	10%	12.5%	15%	0%	7.5%	10%	12.5%	15%
Cement (kg/m^3)	650	601.25	585	568.75	552.5	650	601.25	585	568.75	552.5	650	601.25	585	568.75	552.5
POFA (kg/m^3)	0	48.75	65	81.25	97.5	0	48.75	65	81.25	97.5	0	48.75	65	81.25	97.5
Water	143	143	143	143	143	163	163	163	163	163	175.5	175.5	175.5	175.5	175.5
Sp(kg/m^3)	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75
Fine (kg/m^3)	707	707	707	707	707	694	694	694	694	694	688	688	688	688	688
Coarse (kg/m^3)	899.9	899.9	899.9	899.9	899.9	883	883	883	883	883	876	876	876	876	876

III. RESULTS AND DISCUSSION

Water binder ratio as one of the factors that influenced the performance of compressive strength of concrete was studied at ratios of 0.22, 0.25, and 0.27 at 28 curing age, different POFA percentages and cement contents of 450kg/m^3, 550kg/m^{3,} and 650kg/m^3. The effect of water binder ratio on the performance of pozzolan concrete was studied through a predictive model by fitting experiment data into a linear regression model to ascertain the predictability of compressive strength of POFA concrete at the given cement content and percentage POFA while varying the water binder ratio. The predicted results as compared to experimental results are shown in Table 1, while the linear models are shown in Figures 1 to 5.

TABLE IV
Predicted and experimental compressive strength of concrete at varying POFA percent and cement contents

0 % POFA						
W/B	**450 (kg/m^3)**		**550 (kg/m^3)**		**650 (kg/m^3)**	
	Expt.	Pred.	Expt.	Pred.	Expt.	Pred.
0.22	73.1	73.16	77.2	76.96	83.4	82.77
0.25	68.4	68.26	71.3	71.91	73.2	74.78
0.27	64.9	64.99	68.9	68.54	70.4	69.46
7.5 % POFA						
	Expt.	Pred.	Expt.	Pred.	Expt.	Pred.
0.22	61.4	61.43	64.6	64.95	73.8	73.76
0.25	57.2	57.12	61.6	60.73	65.8	65.89
0.27	54.2	54.25	57.4	57.92	60.7	60.64
10 % POFA						
	Expt.	Pred.	Expt.	Pred.	Expt.	Pred.
0.22	57.2	57.54	58.7	59.03	64.5	64.02
0.25	55.6	54.76	57.8	56.97	57.7	58.89
0.27	52.4	52.91	55.1	55.60	56.2	55.48
12.5 % POFA						
	Expt.	Pred.	Expt.	Pred.	Expt.	Pred.
0.22	50.8	50.69	53.6	53.28	58.4	58.24
0.25	48.3	48.60	48.6	49.40	52.0	52.38
0.27	47.4	47.22	47.3	46.82	48.7	48.47
15 % POFA						
	Expt.	Pred.	Expt.	Pred.	Expt.	Pred.
0.22	48.7	49.03	51.6	51.25	56.5	56.46
0.25	46.1	45.28	46.2	47.07	50.3	50.39
0.27	42.3	42.79	44.8	44.28	46.4	46.34

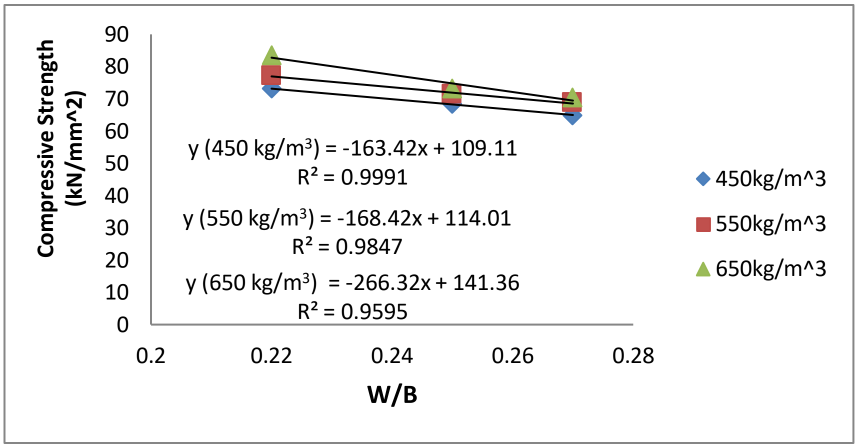

Fig 1: Compressive strength versus water binder ratio at 0% POFA and varying cement content

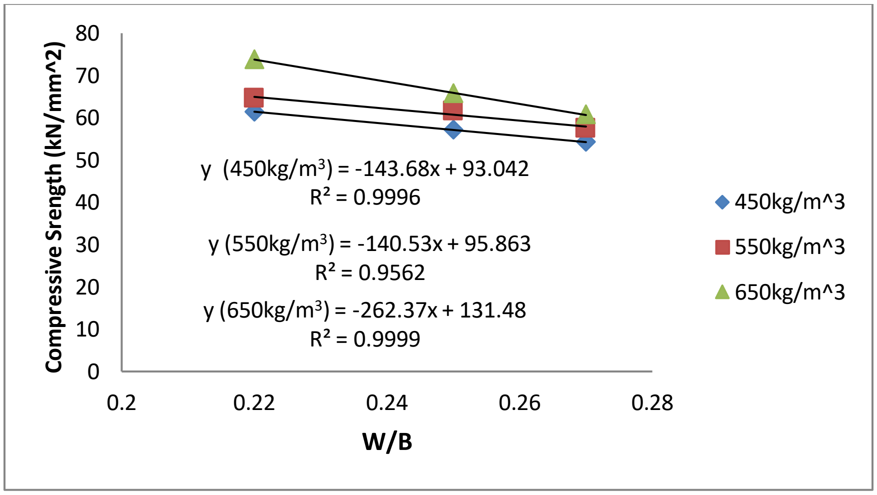

Fig 2: Compressive strength versus water binder ratio at 7.5% POFA and varying cement content

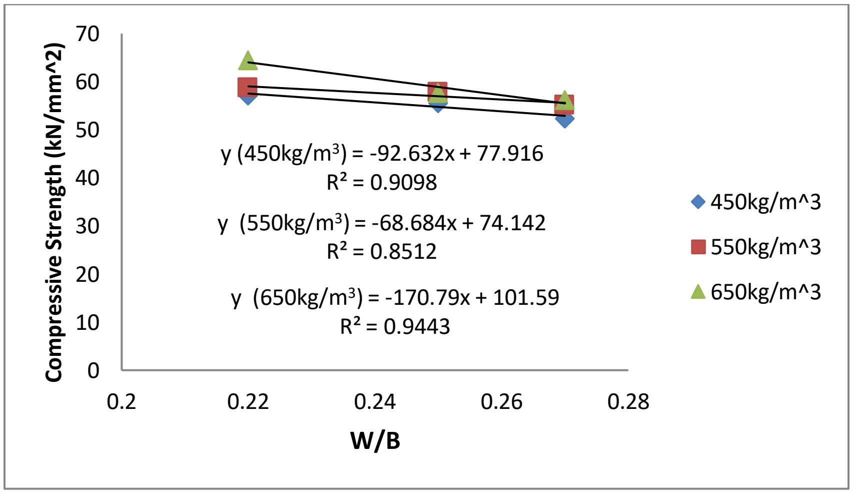

Fig 3: Compressive strength versus water binder ratio at 10% POFA and varying cement content

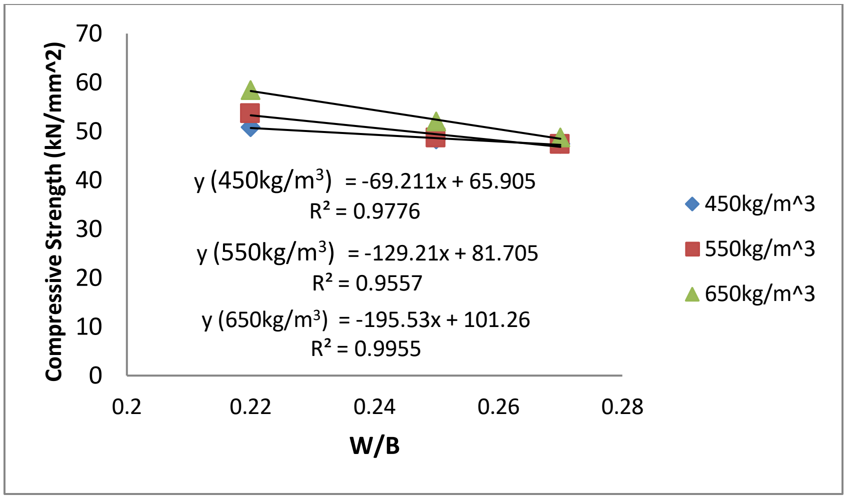

Fig 4: Compressive strength versus water binder ratio at 12.5% POFA and varying cement content

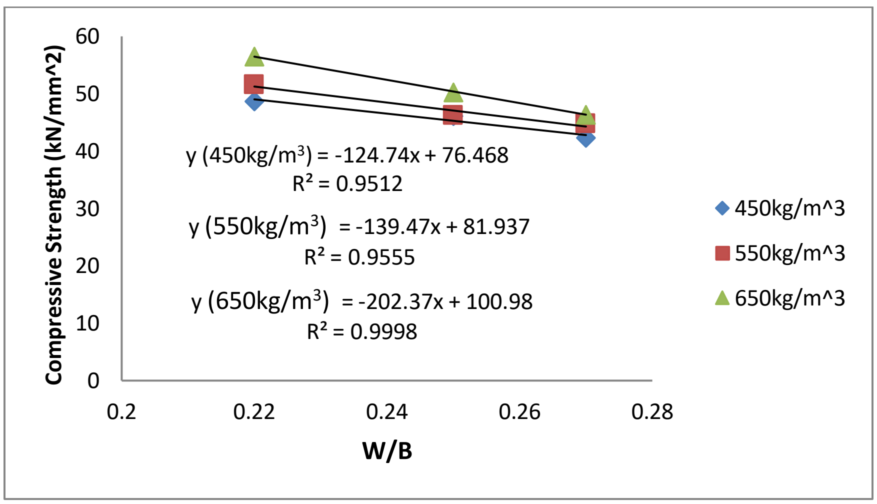

Fig 5: Compressive strength versus water binder ratio at 15% POFA and varying cement content

Figure 1 through Figure 5 showed the compressive strength of POFA concrete as a function of water binder ratio at different cement contents. Again, from the figures, the compressive strengths of concrete decreased with an increase in water binder ratio at any given mixing proportion of the POFA. Hence, at a water binder ratio of 0.22, the compressive strengths of POFA concrete in all the mixes were highest. Also, the values of compressive strength at 0% POFA showed the best performance at 0% POFA and least at 15% POFA in all the mixing conditions investigated. However, the performance was satisfactory at all the proportions of the replacement materials.

Similarly, from the figures, the compressive strength of POFA concrete as a function of water binder ratio can be described by a linear regression equation. As shown in the figures, there was high correlation coefficients, R^2 for all the regression equations, which is an indication that the compressive strength of POFA concrete can be effectively predicted by a simple linear model at any given water binder ratio. The numerical values predicted by the model as against the corresponding measured values are presented in Table IV.

IV. CONCLUSION

The dependency of pozzolan concrete performance on water binder ratio has been demonstrated via a simple linear model. There was a high prediction of POFA concrete by the model, with correlation coefficients, R^2 ranging from 0.8512 to 0.9999. Therefore, the compressive strength of concrete is a function of water binder ratio and obeyed a simple linear equation given as $f_{cu} = w_r x + \beta$.

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