Performance of Super Absorbent Polymer on the Compressive Strength of Concrete Blended with Metakaolin

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Abstract— Due to the ability of high dosage of Super Absorbent Polymer (SAP) to effectively seal cracks in concrete with a resulting decrease in strength, there is a need to find alternative methods of using SAP without much strength loss. The aim of the present study is to evaluate the performance of SAP when blended with Metakaolin (MK). The Absolute Volume method was applied for this study. Hardened state properties of compressive strength was evaluated. Cement replacement with MK was carried out at (4%, 8%, 12% and 16%) and (0.25%, 0.5%, 0.75% and 1%) for SAP. The compressive strength properties is compared for 0.2 % 0.25 water binder ratios at 7, 14 and 28 days. The result showed that the use of MK and SAP improves the compressive strength properties of concrete. The optimum results were observed at 12% MK and 0.5% SAP. The maximum comprehensive strength at 28 days was found to be 91.51 Mpa and 84.99 Mpa for 0.2 w/b % 0.25 w/b respectively. A decrease in strength was observed as the dosage of SAP exceeds 0.5% replacement.

Indexed Terms— Super Absorbent Polymer, Metakaolin

I. INTRODUCTION

Throughout the last two decades, crack in concrete has been a major concern in structural engineering. Cracks are a common phenomenon due to moderately low tensile strength and other factors including early age shrinkage and loading [40]. This cracking related deterioration seriously influences the integrity and durability of the concrete [41].

In mitigating cracks that could possibly occur in HSC, great advance in concrete technology have risen to a large extent out of the development and use of new chemical additives which although added to concrete in very small quantities can dramatically improve crucial properties of concrete in its fresh and harden state [10]. One prominent example is the use of Super Absorbent Polymers (SAP).

The introduction of Superabsorbent polymers (SAP) as a new component for the production of concrete materials offers a number of new possibilities with respect to water control and, as a result, to the control over the rheological properties of fresh concrete, this in addition to purposeful water absorption and/or water release in either fresh or hardened concrete [42]. Mixing SAP with concrete not only improves its water tightness capability, but also provides the concrete with internal curing moisture it needs to improve its strength [8].

“Reference [35]” carried out a study using super absorbent polymers in concrete focusing on strength and shrinkage of the concrete. He concluded that the shrinkage of concrete due to loss of water is the cause of cracking both in the plastic and in the hardened state. This type of cracking can effectively mitigated by slowing down the water loss. The superabsorbent polymers use in concrete has the potential to reduce concrete cracking.

“Reference [7]” studied the use of Sodium Polyacrylates as SAP in concrete. In his study, the optimum amount of SAP that is to be added to the concrete in order to maximize the strength and durability of concrete was determined. From the results, it was concluded that the optimum amount of

SAP is 0.11% of cement by weight, which he showed to be the most effective amount to be used in concrete. In a recent study by [40], the potential of super absorbent polymers (SAPs) to self-seal cracks was investigated via transport experiments, microscopy and modeling. Samples containing SAPs of 0.3mm cracks were subjected to 0.12wt% NaCl at 4m/m pressure gradient to stimulate ground water seepage. Result showed that SAP can re-swell and seal cracks reducing peak flow and total flow by 85% and 98% respectively. It was also observed that increasing the SAP dosage accelerates sealing but imparts a strength penalty and thereby limiting practical applications.

AIM AND OBJECTIVE

The purpose of this research is to study the influence of SAP and the effective contribution of MK as partial replacement of cement on the workability, strength and durability properties of High Strength Concrete (HSC). The main objectives of the study includes:

i. To study the influence of SAP and MK on the workability of HSC.
ii. To determine the optimum dosage of SAP needed in HSC.
iii. To investigate the compressive and tensile strength
iv. To develop a predictive strength model for determining its functional relationship with other concrete constituent.
v. To develop a mix design based on Super absorbent polymer and Metakaolin as partial replacement of cement for compressive and tensile strength of high strength concrete

II. LITERATURE REVIEW

The following literature review below were observed in extent past work.

“Reference [34]” experimented on the use of SAP as an internal curing agent and how it affects the compressive strength of mortar and came up with the conclusion that SAP tends to promote internal curing and that there was a decrease in the compressive strength at 28days by 4.74% which was not the same case for mixes without SAP.

“Reference [32]” evaluated experimentally the hysteresis in the swelling behavior of spherical super absorbent polymers (SAPs) on rapid self-sealing of cracks in cementious materials under wet/dry cycles (swelling/de-swelling) using tea-bag method and water flow test. The water flow test result showed that the mean reduction ratios in water run off through cracks for the cracked specimens containing spherical SAP particles were 0.278 and 0.367 for SAP dosages of 0.5% and 1.0% in 1-cycle respectively. And as the wet/dry cycles were repeated and the ratios gradually increased to about 1.75 times and 1.99 times of those of the 1-cycle respectively. Therefore it was concluded that SAPs can repeatedly exhibit rapid crack self-sealing performance in cementious material.

[10] examined the effect of super absorbent polymer in concrete. After series of laboratory investigation and analysis of results, they observed that the compressive strength, flexural and tensile strength of concrete is increased for 0.3% SAP as compared to conventional concrete. Also as the SAP dosage exceeds 0.3% SAP there is a decrease in the compressive strength and an increase in the workability of the concrete is obtained. They also discovered that the formation of cracks is more in the case of concrete with SAP than concrete without SAP addition.

“Reference [38]” carried out an experimental study on the use of an optimum amount of sodium polyacrylate as a super absorbent polymer for self-curing of concrete. Several batches were prepared to determine the effect of the SAP on the concrete and when subjected to compressive, tensile and flexural stresses. Addition of SAP leads to a significant increase of compressive, tensile and flexural strengths.

“Reference [52]” experimented on the effect of metakaolin on the properties of concrete. Based on their experimental observations, it was deduced that metakaolin increases the compressive and flexural strength effectively as compared with conventional concrete and workability decreases as percentage of metakaolin in concrete increases. The strength of concrete increases with increase in metakaolin content up to 15% replacement of cement. And finally as the percentage of metakaolin powder in concrete increases, workability of the concrete decreases.

"Reference [32]" experimented on effect of metakaolin as a partial replacement for cement on the compressive strength of high strength concrete at varying water/binder ratios. At 10% replacement of cement with metakaolin at 0.2 water-cement ratio, the maximum value of compressive strength (95.33 MPa) was measured at 28 days of water curing. Metakaolin was observed to increase the compressive strength by 28.85% at 10% replacement level at 7 days curing.

III. METHODOLOGY

A. Material Selection

In this research, materials used were chosen according to the specification that meets the requirement of the British Standards as well as the objective of this study.

- Super absorbent polymer used in this research is the sodium polyacrylate. Properties (Chemical composition) of SAP is shown in Table 1. SAP obtained had particle size ranging from 0-2mm with density of 1.40g/cm^3.
- Coarse aggregate used in this experiment is natural granite aggregates of maximum size (20mm) from crushed rock industries in Port Harcourt conforming to BS 812-103.2 1989.
- Fine aggregate used is the river sand obtained from Choba River in Emouha Local Government Area, Rivers state Nigeria meeting the requirement and specification of BS 882 (1992). Fractions from 4.75mm sieve are termed as fine aggregates.
- Ordinary Portland cement manufactured by Dangote Cement Company (Conforming to EN 196 – 1:1987)
- Portable water from the university mains conforming to BS 3148 (1970).
- Metakaolin
- Super plasticizer (SP), a polycarboxylate ether PCE based super plasticizer was adopted. The dosage level was within 1.2% of the total cement content conforming to EN 934 – 2. It was used as an additional material to enhance viscosity of the mixes.

The sample preparation and compressive strenght tests were carried out in the structural laboratory, department of Civil Engineering, Rivers State University.

- Test Procedure

Compressive strength and tensile strength test was performed on concrete samples in accordance with BS EN 12390-3:2002 using Digital Compressive tensile testing machine. Three concrete cubes at ages 7, 14, and 28 days were tested.

- Design of Mix Proportions

Ordinary Portland cement was used in the research as a base binder for all mixes. Metakaolin was used as an admixture to improve the strength. Metakaolin was used to replace cement by 4%, 8%, 12% and 16%. Sodium polyacrylate was replaced by 0.25%, 0.5%, 0.75% and 1% by cement. All other material quantities were kept constant in order to see the effect of replacement of MK and SAP on the properties of concrete.

The Absolute volume method Mix design procedure was adopted in accordance with BS8110. Assumed a suitable water/cement ratio and determine the target strength based on the curing age as presented below.

- Determination of the free water-cement ratio: This can be obtained directly from chart in Figure 1. The curve shows an inverse relationship between mean compressive strength and the water/cement ratio at different curing ages.
- Alternatively, the empirical relationship of Equation 1 can be used to compute the compressive strength at a specified water/cement ratio.

$$f_c = \frac{140.44}{(10.92)^{w/c}} \quad (1)$$

Water content is obtained from the table below based on the expected slump value. For the purpose of strength, the water content is lower than 180 kg/m3.

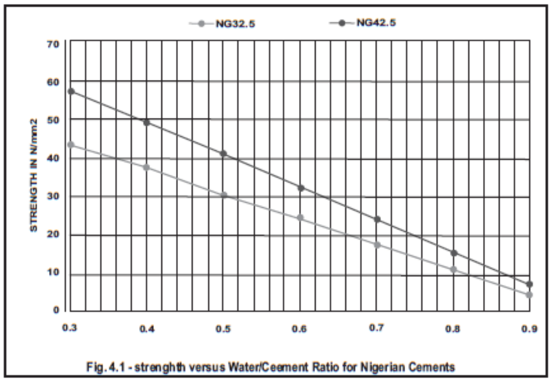

Figure1: Compressive Strength-Water/Cement Ratio Curve

IV. RESULTS & DISCUSSIONS

The result for the compressive strength of concrete cubes at water-cement ratio of 0.2 and 0.25 after curing for 7, 14 and 28 days are presented in Table 2 below. These results are further plotted against Metakaolin replacement at the different levels of SAP dosage. The variation in compressive strength for specimen containing Super Absorbent Polymer (SAP) and Metakaolin (MK) at different percentage dosage level are plotted for the various curing ages. From Table 2, it is observed that the highest compressive strength value of 95.33 MPa is exhibited by the concrete sample with 0.20 water-cement ratio and 10% replacement of cement with Metakaolin.

At 7 days curing age, it was observed that the compressive strength of the concrete at 0.2 w/c ratio increases slightly above the control as the amount of SAP and metakaolin increases. (i.e. above 0% replacement of the ordinary Portland cement with metakaolin and 0% inclusion of SAP). The strength increased with increase in SAP content. At 0.5% inclusion of SAP the strength increased to about 9.37% and then decreased with further increase in SAP to about 12.58% at 1% inclusion of SAP. The maximum compressive strength value was observed to be 87.32MPa at 12% metakaolin and 0.5% SAP for 0.2w/b. Then at 12% MK and 1% SAP the compressive strength observed was (80.792MPa) which is lower than that at 12%MK and 0%SAP (81.39MPa). It is evident to say that the compressive strength of concrete without SAP is higher than that with 1%SAP inclusion.

Table 1: Summary of Mix Ratio for Research.

Mix	MK%	SAP%	SP%	Cement (kg/m3)	Fine Agg.(Kg/m3)	Coarse Agg. (kg/m3)	Mk (kg/m3)	SAP (kg/m3)	Water
0.2	0	0	1.2	620	711.24	1049.67	0	0	124
	4	0.25	1.2	586.21	711.24	1049.67	33.79	1.55	124
	8	0.5	1.2	559.86	711.24	1049.67	60.14	3.1	124
	12	0.75	1.2	533.51	711.24	1049.67	86.49	4.65	124
	16	1	1.2	507.16	711.24	1049.67	112.84	6.2	124
0.25	0	0	1.2	496	756.28	1116.14	0	0	124
	4	0.25	1.2	468.97	756.28	1116.14	27.03	1.24	124
	8	0.5	1.2	447.89	756.28	1116.14	48.11	2.48	124
	12	0.75	1.2	426.81	756.28	1116.14	69.19	3.72	124
	16	1	1.2	405.73	756.28	1116.14	90.27	5.27	124

Table 2: Compressive Strength Result for Concrete Mixtures under Different Curing Ages.

Days	W/C	%SAP	CS at 0%MK	CS at 4%MK	CS at 8%MK	CS at 12% MK	CS at 16% MK
7days	0.2	0	56.58	72.29	74.1	76.39	73.93
		0.25	55.45	76.7	77.43	79.14	75.22
		0.5	57.66	78.59	81.29	82.32	78.41
		0.75	55.22	71.27	73.9	78.89	73.28

		1	53.99	69.33	72.38	75.79	69.98
	0.25	0	51.33	64.12	67.89	71.46	68.37
		0.25	52.21	68.45	68.74	72.54	69.84
		0.5	52.99	70.35	71.8	74.25	72.45
		0.75	50.67	65.29	66.5	70.76	69.42
		1	49.58	61.78	64.2	67.34	65.22
14days	0.2	0	61.64	74.86	76.65	81.46	78.33
		0.25	62.92	75.17	77.43	84.9	79.19
		0.5	64.11	77.25	81.29	86.24	80.92
		0.75	62.21	76.27	79.9	81.18	76.38
		1	60.28	69.33	72.38	73.64	73.38
	0.25	0	57.22	67.23	70.68	77.51	75.7
		0.25	57.89	68.42	72.29	79.12	76.69
		0.5	59.29	70.28	73.26	80.24	78.2
		0.75	58.44	68.14	71.88	78.39	77.31
		1	58.02	67.18	70.11	77.35	75.7
28days	0.2	0	71.22	82.44	84.11	86.25	83.45
		0.25	72	83.49	86.1	87.41	84.74
		0.5	74.65	84.19	87.55	91.51	85.24
		0.75	74.44	83.86	82.38	84.62	82.34
		1	73.65	77.28	80.29	82.17	80.36
	0.25	0	65.35	83.22	78.36	80.32	78.7
		0.25	67.43	77.38	80.49	81.56	80.45
		0.5	69.87	79.48	83.79	84.99	81.55
		0.75	68.77	77.89	80.11	82.25	80.01
		1	64.22	75.19	77.51	79.82	76.79

Furthermore, a similar trend is observed for the second mix of 0.25w/c ratio. This is shown in figure 4.3 below. The maximum compressive strength observed was 69.25MPa at 0.5% SAP and 12% MK.

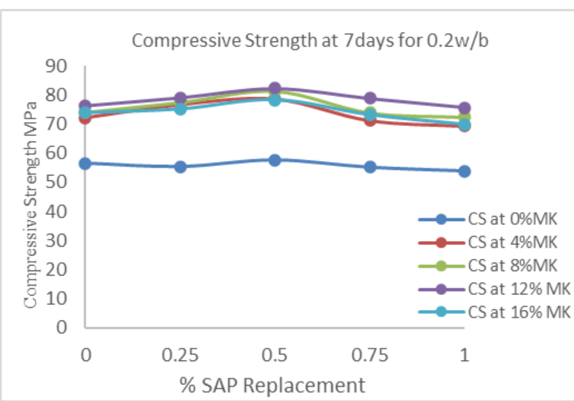

Figure 2: Graph of Compressive Strengths of Samples after 7 Days Curing

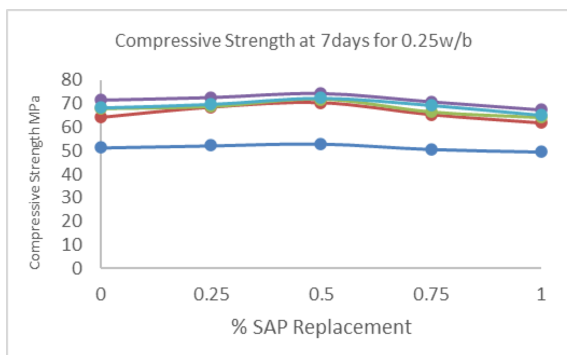

Figure 3: Graph of Compressive Strengths of Samples after 7 Days Curing

At 14 days curing age, a similar trend was also observed for the compressive strength test. The maximum compressive strength test value for control was observed to be 66.64MPa. The highest recorded strength for 0.2w/b and 0.25w/b with respect to the addition of the SAP and replacement of ordinary Portland cement with metakaolin was 91.24MPa and

85.24MPa respectively at 12% replacement of OPC with MK and 0.5% inclusion of SAP. The graphs are shown below.

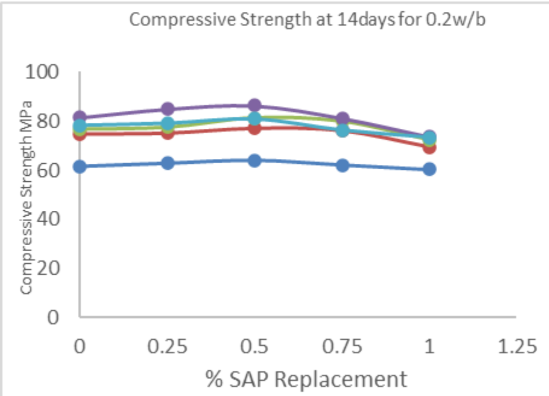

Figure 4: Graph of Compressive Strengths of Samples after 14 Days Curing

At 14 days curing age, a similar trend was also observed for the compressive strength test. The maximum compressive strength test value for control was observed to be 66.64MPa. The highest recorded strength for 0.2w/b and 0.25w/b with respect to the addition of the SAP and replacement of ordinary Portland cement with metakaolin was 91.24MPa and 85.24MPa respectively at 12% replacement of OPC with MK and 0.5% inclusion of SAP. The graphs are shown below.

From the figure above, it is observed that the compressive strength increases slightly from the control up to 12%MK and then reduces at 16%MK replacement. At a constant replacement of MK and gradually increasing the SAP dosage, the compressive strength increases to its maximum at 0.5% SAP and then reduces for 0.75% and 1% SAP dosage.

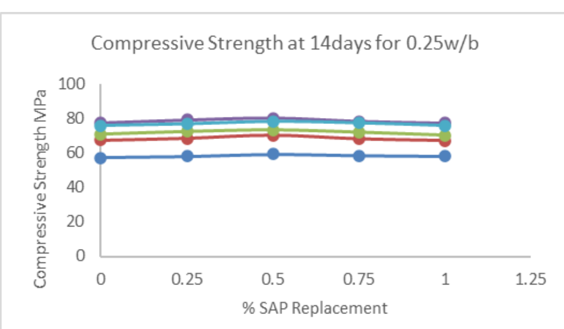

Figure 5: Graph of Compressive Strengths of Samples after 14 Days Curing

The maximum compressive strength observed is 89.24MPa for a SAP dosage of 0.5% at 12%MK. A slight decrease in strength was observed as the SAP exceeds 0.5% dosage and also at 16%MK. Similar pattern for the compressive strength was also observed at day 0.25w/c ratio. The graph for 14days compressive strength at 0.25w/c ratio is shown below.

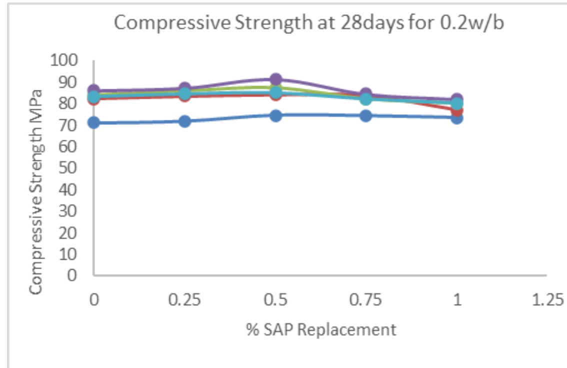

Figure 6: Graph of Compressive Strengths of Samples after 28 Days Curing

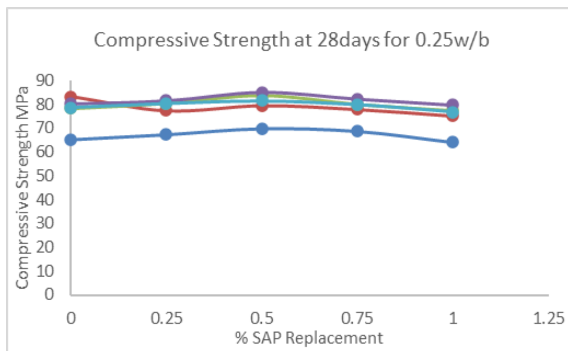

Figure 7: Graph of Compressive Strengths of Samples after 28 Days Curing

V. FINDINGS AND CONCLUSION

The aim of this research was to determining the performance and the mechanical properties of Super Absorbent polymer for Self-sealing of cracks in High strength concrete blended with Metakaolin. This was achieved through the ability of SAP to seal cracks and induce internal curing. The cementitious efficiency of metakaolin was also explored as a partial replacement material for cement in the production of HSC to potentially increase the strength of concrete.

The functional relationship between the inputs variables (concrete constituents and curing age) are examined in plethora of detail. Based on the experimental and analytical results, the following conclusions can be drawn;

- The Absolute Volume Method (Mix Design) provided a satisfactory result for fresh and hardened state properties.
- The maximum compressive strength value of 91.51Mpa is achieved at 28 days for 0.2 water-cement mix ratio at 12% replacement of ordinary Portland cement with Metakaolin and 0.5% sodium polyacrylate. Also the maximum compressive value at 28 days is 84.99Mpa for 0.25 water/cement ratio having a SAP content of 0.5%. It was observed that the compressive strength increases as the SAP dosage increases up to 0.5% replacement and then gradually decreases as the SAP increases above 0.5%. The compressive strength at 1%SAP replacement is lesser that the compressive strength without SAP inclusion.
- The optimum dosage for SAP in concrete when blending with Metakaolin is 0.5% for higher compressive strength.
- In the range of 4 – 16 wt. % cement replacement, metakaolin was very effective in improving compressive strength of HSC blended with SAP. Therefore, the underlying design of the HSC could be successfully based on the proposed value range of the efficiency factor for metakaolin.

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