Tensile Strength and Workability of High Strength Concrete Using Super Absorbent Polymer and Metakaolin as Partial Replacement for Cement

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Abstract*— The use of superabsorbent polymers (SAP) as an internal curing (IC) agent in concrete is one method for reducing autogenous shrinkage. Micro-voids formed by SAP are thought to be harmful to the concrete's mechanical qualities, particularly its compressive strength. The results of an experimental research of SAP's effect on the splitting tensile strength and workability of low water/binder (W/B) high strength concrete are presented in this paper (HSC). Because high doses of Super Absorbent Polymer (SAP) may successfully fill cracks in concrete while reducing strength, there is a need to identify alternate techniques of employing SAP that do not result in significant strength loss. The purpose of this study is to see how SAP performs when combined with Metakaolin (MK). This research used the Absolute Volume technique. Tensile strength characteristics in the hardened condition were assessed. For the experiment, SAP, MK was used to replace cement at a rate of (4 percent, 8 percent, 12 percent, and 16 percent) and (0.25 percent, 0.5 percent, 0.75 percent, and 1 percent). At 28 days, the tensile strength parameters of 0.2 percent 0.25 water binder ratios are compared. The addition of MK and SAP improved the tensile strength qualities of concrete, according to the findings. At 12 percent MK and 0.5 percent SAP, the best results were obtained. For SAP dose of 1% and Metakaolin dosage of 12%, the highest tensile strength was 4.45Mpa and 4.21Mpa at 0.2w/b and 0.25w/b after 28 days. When the dosage of SAP is more than 0.5 percent replacement, the strength increases.

***Indexed Terms*— Super Absorbent Polymer, Metakaolin**

I. INTRODUCTION

High-strength concrete (HSC) is a kind of concrete that fulfils stringent performance and consistency standards. High-strength concrete cannot be achieved only via the use of standard components and mixing techniques. "High-strength concrete" is described by the American Concrete Institute as "concrete that meets unique performance and uniformity requirements that cannot always be met routinely using conventional components and standard mixing, pouring, and curing practices." Low water to binder ratio (w/b) can be used to make high-strength concrete. High early strength, improved mechanical characteristics, and extended life in a demanding environment may be performance requirements for developing a concrete with high strength. Concrete with a compressive strength of more than 40 MPa after 28 days of curing is classified as high-strength concrete [11].

In mitigating cracks that may occur in HSC, great advances in concrete technology have resulted, in large part, from the development and use of new chemical additives, which, when added to concrete in very small quantities, can dramatically improve critical properties of concrete in its fresh and hardened states [10]. The usage of Super Absorbent Polymers is one such example (SAP).

The addition of Superabsorbent polymers (SAP) as a new component for the production of concrete materials opens up a plethora of new possibilities for water control and, as a result, control over the rheological properties of fresh concrete, in addition to purposeful water absorption and/or water release in either fresh or hardened concrete [42]. When SAP is mixed with concrete, it not only enhances its water tightness, but it also gives the concrete with the internal curing moisture it requires to strengthen [8].

According to [54], the tensile strength of SAP specimens reached 0.41 MPa, compared to 0.35 MPa for conventional specimens. It was determined that the inclusion of SAP material improves the cracking resistance of the concrete. This was mostly due to SAP expanding into gel following water absorption, which lies between the cement particles and the aggregate and can partially enhance the binder's workability as well as densify the internal structure.

According to [55], the splitting tensile strength of concrete under two water–cement ratios demonstrated that the SAP concentration and splitting tensile strength of the concrete were inversely related when the water-cement ratio and particle size were held constant. This was due to the SAP being particularly water-absorbent and swelling with water at the start of the concrete's hydration process. With the strengthening of the hydration reaction, the water inside the SAP was sucked away by the surrounding medium to leave pores.

The greater the SAP content, the larger the concrete pores. The splitting tensile strength of concrete tended to increase firstly and then decrease with an increase in the particle size. The loss of concrete splitting tensile strength at the w/c ratio of 0.3 and 0.7 was 10.23% and 17.64%, respectively, which was similar to the research results of [42].

Previous studies have found an inversely proportionate link between SAP concentration and concrete mechanical properties such as compressive strength, flexural strength, elastic modulus, and splitting tensile strength. The mechanical characteristics of concrete tend to rise initially and subsequently decline as the SAP particle size increases.

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 tensile strength.

II. LITERATURE REVIEW

The establishment of a resource-saving approach is critical for sustainable growth in concrete engineering. Improving construction quality and operational performance has been central to the evolution of concrete engineering construction. The following literature review below were observed in extent of past work.

Previous study investigations evaluated SAP's internal curing influence in two ways. What are the physical and mechanical properties, as well as volume stability, durability, and microstructure? Second, substantial research has been conducted on the interaction between the internal curing of SAP and the steel fibre. The goal of this study is to look into the impact of SAP particle size and content on the workability and tensile strength of concrete in different mixing amounts.

"Reference [38]" conducted an experimental investigation to determine the optimal quantity of sodium polyacrylate to utilize as a super absorbent polymer for self-curing concrete. Several batches of concrete were made to test the effect of the SAP on the concrete when subjected to compressive, tensile, and flexural stresses. The use of SAP increases compressive, tensile, and flexural strengths significantly.

Using the tea-bag technique and a water flow test, [32] investigated the effect of hysteresis in the swelling behavior of spherical super absorbent polymers (SAPs) on fast self-sealing of cracks in cementious materials during wet/dry cycles (swelling/de-swelling). The mean decrease ratios in water runoff via cracks for cracked specimens containing spherical SAP particles were 0.278 and 0.367 for SAP doses of 0.5 percent and 1.0 percent in 1-cycle, respectively, according to the water flow test results. The ratios rapidly rose when the wet/dry cycles were repeated, reaching roughly 1.75 times and 1.99 times of the 1-cycle ratios, respectively. As a result, it was determined that SAPs can display quick fracture self-sealing capability in cementious materials on a consistent basis.

“Reference [52]”, studied and experimented on the effect of metakaolin on the properties of concrete Based on experimental observations, following conclusions can be drawn: Metakaolin concrete increases the compressive, tensile and flexural strength effectively as compared with conventional concrete. 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. As the Percentage of metakaolin powder in concrete increases, workability of concrete decreases.

“Reference [53]” studied the high strength concrete by partial replacement of cement by fly ash, metakaolin and alccofine. All the concrete mixes made with different replacement levels of metakaolin and alccofine by weight of ordinary Portland cement showed higher compressive strength as compared to concrete mix made with ordinary Portland cement. There were increase in flexural strength of concrete by replacement of cement by metakaolin and alccofine by 7% and of cement by metakaolin and alccofine by 7%

III. METHODOLOGY

A. *Material Selection*

The materials utilized in this study were chosen based on a specification that met the requirements of British Standards as well as the study's goal.

- The sodium polyacrylate is a super absorbent polymer that was employed in this study. SAP with particle sizes ranging from 0 to 2mm and a density of 1.40g/cm3 was used.
- Natural granite aggregates of maximum size (20mm) from crushed rock businesses in Port Harcourt, according to BS 812-103.2 1989, were utilized as coarse aggregate in this experiment.
- 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 structural laboratory of Rivers State University's Department of Civil Engineering performed the sample preparation and compressive strength tests.

- Test Procedure

Using a Digital Compressive Tensile Testing Machine, concrete samples were tested for tensile strength in line with BS EN 12390-3:2002. The concrete cubes were examined at 28 days.

- Design of Mix Proportions

All mixtures in the study were made with ordinary Portland cement as a base binder. To boost the strength, metakaolin was used as an additive. By 4 percent, 8 percent, 12 percent, and 16 percent, metakaolin was employed to replace cement. Cement was used to replace sodium polyacrylate in the proportions of 0.25 percent, 0.5 percent, 0.75 percent, and 1 percent. To assess the effect of replacing MK and SAP on concrete qualities, all other material amounts were maintained unchanged.

In line with BS8110, the absolute volume technique Mix design approach was used. Assumed a good water/cement ratio and calculated the goal strength using the curing age as shown below.

- Determining the free water-to-cement ratio: This may be done simply from Figure 1's chart. At various curing ages, the graph reveals an inverse connection between mean compressive strength and the water/cement ratio.
- Alternatively, the empirical relationship presented by (Lydon, 2002) may be used to calculate compressive strength at a given water/cement ratio.

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

Based on the projected slump value, the water content is calculated using the table below. The water content is less than 180 kg/m3 for the purpose of strength.

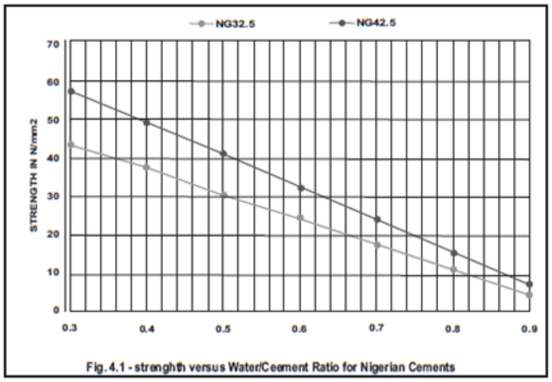

Figure1: Compressive Strength-Water/Cement Ratio Curve

IV. RESULTS & DISCUSSIONS

- Split Tensile Strength

The result for the tensile strength of concrete cubes at water-cement ratio of 0.2 and 0.25 after curing for 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 tensile 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 above it is observed that the tensile strength is maximum at 12% replacement of metakaolin with SAP dosage of 1% with a value of 4.43MPa at a water-cement ratio of 0.2. It was observed that the tensile strength increases with increase in SAP dosage.

The split tensile strength value of concrete increase in with increases percentages of cement replacement with super absorbent polymer and metakaolin up to a percentage of 1% and 16% for SAP and MK respectively.

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.

W/C	%SAP	STS at 0%MK	STS at 4%MK	STS at 8%MK	STS at 12%MK	STS at 16%MK
0.2	0	3.10	3.38	3.42	3.57	3.52
	0.25	3.35	3.52	3.61	3.79	3.54
	0.5	3.60	3.76	3.83	3.92	3.59
	0.75	3.88	4.00	4.15	4.28	3.64
	1.0	4.26	4.22	4.35	4.43	3.73

0.25	0	2.94	3.32	3.36	3.45	3.41
	0.25	3.24	3.44	3.56	3.68	3.53
	0.5	3.43	3.61	3.69	3.81	3.71
	0.75	3.59	3.77	3.72	3.95	3.77
	1.0	3.84	3.92	3.89	4.21	3.72

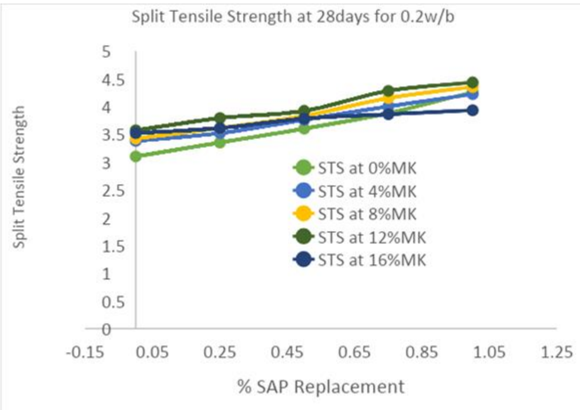

Figure 2: Graph of Tensile Strengths of Samples after 28 Days Curing at 0.2w/b.

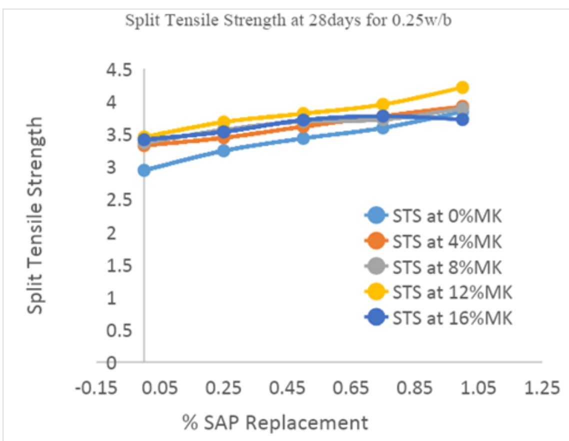

Figure 3: Graph of Tensile Strengths of Samples after 28 Days Curing at 0.25w/b.

It can be seen that the splitting tensile strength of the control and modified concrete increases with increase in both SAP and MK. The results show that the modified concrete with 16% partial replacement of cement by metakaolin and addition of 1% super absorbent polymer resulted in an enhanced splitting tensile strength compared with the control concrete. A change in the splitting tensile strength was observed for 0.25w/b compared to 0.2w/b. The highest splitting tensile strength of the modified concrete was obtained for the 0.2w/b mix. The results also show that the addition of super absorbent polymer improves the splitting strength about 15%-25%. Concrete sample having SAP and without metakaolin had high tensile strength compared to concrete with metakaolin and SAP.

From the results it can also be seen that similar to compressive strength the splitting tensile strength also exhibited the highest strength at 12% MK. It can be observed that as the compressive strength increases the tensile strength also increases and at 16% MK both compressive and tensile strength reduces.

The highest value of the 28-day tensile strength for the concretes was about 4.43MPa, which corresponds to 5.39 % of the compressive strength for the same concretes.

- Slump Flow Test

In the slump test experiment, the diameter of the flowing concrete was obtained in two perpendicular directions and then the average results taken. The highest slump value was recorded for 0.25w/b at a SAP replacement of 1% and metakaolin replacement of 4%. It was observed that as the MK content increased the slump gradually reduces. For every increment in the SAP content the slump value increases also. For MK of 4% and SAP of 0.25 the slump was observed to be 13mm and for 16% MK and 1% SAP the slump was observed to be 16mm, this is as a result of SAP gradually releasing water over time.

Table 3: Slump values of the different mixtures using %SAP and %MK

Mix	SAP		Metakaolin		
0.2		4%	8%	12%	16%
	0.25	13	12	12	10
	0.5	14	14	13	13
	0.75	16	15	15	14
	1.0	17	17	16	16
0.25	0.25	13	12	11	10
	0.5	15	15	13	13
	0.75	16	14	14	13
	1.0	18	18	16	16

The Table 3 above shows the slump values for 0.2w/b and 0.25w/b at various cement replacement with super absorbent polymer and metakaolin. For the two water/cement ratios it was observed that 0.25w/b had higher slump values compared to 0.2w/b ratio. At 8% MK and 1% SAP the highest slump value was 18mm for 0.25w/b compared to 17mm slump for 0.2w/b. Therefore by increasing the water binder ratio the slump increases. It is important to note that as SAP increases the slump increase also which is as a result of the SAP releasing absorbed water gradually with time as the surrounding humidity drops. This facts is in line with [32] experiments on swelling behavior of super absorbent polymer.

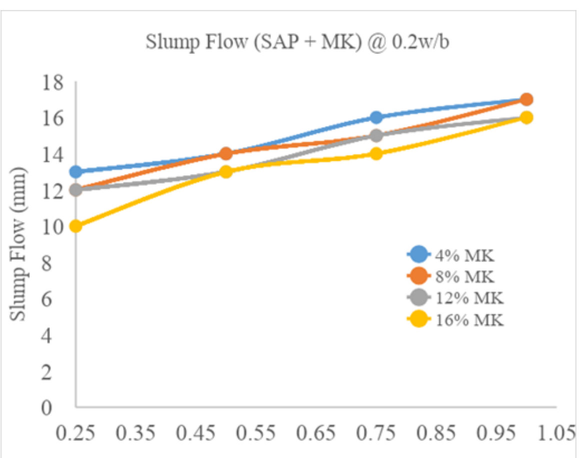

Fig 4 Slump Distribution of Concrete with SAP and MK Content for 0.2w/b.

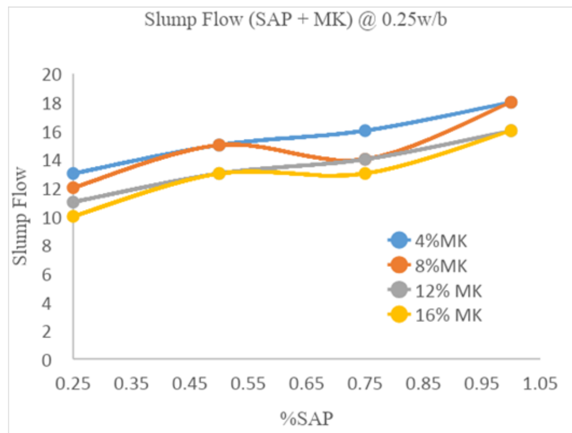

Fig 5 Slump Distribution of Concrete with SAP and MK Content for 0.25w/b.

Figure 4 above shows the variation of slump with SAP and MK at various percentages replacement with cement. It was observed that as the percentage of SAP increases the Slump increases and also as the metakaolin increases the slump reduces. The lowest slump was observed at 16% metakaolin replacement.

From figure 5, it was also observed that as the percentage of SAP increases the Slump increases and also as the metakaolin increases the slump reduces. The highest slump values was observed at 4% and 8% metakaolin and 1% SAP replacement. For 8%MK and 0.75 SAP a sudden drop in slump value was observed as shown on the graph in figure 4.4. Similar trend was also observed for 16% MK at 0.75% SAP replacement. For 4% and 12%MK replacement the slump increases in direct proportion to the increase in SAP dosage.

V. FINDINGS AND CONCLUSION

The goal of this study was to determine the performance and tensile strength qualities of a Super Absorbent polymer for self-sealing cracks in high-strength concrete containing Metakaolin. This was made possible by SAP's capacity to seal fissures and promote internal cure. Metakaolin's cementitious efficiency was also investigated as a partial replacement material for cement in the manufacturing of HSC, with the goal of potentially increasing concrete strength.

The following conclusions can be formed based on the experimental and analytical findings;

- The Absolute Volume Method (Mix Design) provided a satisfactory result for fresh and hardened state properties.
- The tensile strength is maximum (4.43MPa) at 12% replacement of metakaolin with SAP dosage of 1% at a water-cement ratio of 0.2. It was observed that the tensile strength increases with increase in SAP dosage.
- 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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