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Effect of Admixtures on Strength and Permeability of Concrete

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ABSTRACT
This study investigates the effect of admixtures on the compressive strength and permeability of concrete. Five mixes comprising of a control mix and four modified mixes using the following admixtures: accelerator, water proofer, two superplasticizers namely- Sulphonated Naphthalene Formaldehyde condensates (SNF) and a Poly carboxylate Ether (PCE). The control mix was designed for a grade 30 concrete with a water cement ratio (w/c) of 0.55. To maintain constant slump, the w/c ratio was reduced on application of the admixtures. Compressive strength test was carried out at 3, 7 and 28 days; while Initial Surface Absorption Test ISAT and High Pressure Permeability Tests HPPT were both carried out after 28days. Results indicate that SNF and PCE superplasticizer can be used to enhance exceedingly the performance and durability of concrete.
KEYWORDS:*Compressive Strength, Durability, water cement ratio, admixtures.*

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I. INTRODUCTION

There are far more concrete structural problems associated with poor durability than there are due to low compressive strength[1] . As a result, it becomes imperative that concrete be designed for durability. However, this is not the case as compressive strength remains the primary criterion for concrete quality. [2]cited that mix designs have been tailored towards strength: this according to him can be seen in the selection of water/cement ratio which is related or converted to strength. The reason for this is not far-fetched as [3] argued that the concept of strength cuts across other properties of concrete, according to him, increase in strength generally increases- density, impermeability and durability. Strength gives an overall picture of concrete quality because of its direct relationship with the structure of cement paste [4]. Thus, compressive strength and durability to an extent, seem inseparable.

Durability issues of concrete usually involve aggressive fluids moving from the surrounding environment into the concrete through the cover concrete and then acted upon by some physical and/or chemical reaction in its internal structure, thereby leading to deterioration[5] . The mechanisms of ingress of harmful materials involved are in fluid form or dissolved in water, thereby making water an agent of deterioration. Water is responsible for most physical and chemical degradation-cum-durability problems: both directly, eg freeze-thaw action and indirectly by permitting the ingress of aggressive ions[6]. It then follows that one of the most promising evaluation methods regarding concrete durability is water penetration based tests. To this end, it becomes imperative that concrete be made as impermeable as possible. From the first line of defence which is the cover-crete to the concrete core should be made waterproof or impermeable.

The effect of admixtures in this regards cannot be overemphasized. Admixtures have increased both compressive strength and durability of concrete through their water/cement (w/c) reduction, hydrophobic effect, pore reduction/blocking, increased density etc. This has tremendously increased their use in the construction industry today. This work will be examining comparatively the effect of commonly used admixtures such as superplasticizers, accelerators and water proofers on the compressive strength and durability of concrete vis-à-vis its water permeation with and without pressure.

II. SIGNIFICANCE OF STUDY

Concrete durability issues could be broadly classified into two aspects: first is the force instigating damage and secondly is the material resistance/response to the damaging force[7] . As already pointed out, water remains the vehicle/force with which aggressive fluids and chemicals permeate concrete[5], [6]. Thus, water Permeability is often seen as the most important indices to measure concrete durability[8], [9]. A typical example is the corrosion of steel which is regarded as the leading cause of deterioration in concrete[10]. The rust from corroding steel occupies a greater volume than the steel. This causes expansion and creates tensile stresses in the concrete, which can eventually cause cracking, delamination and spalling.

On the other hand, the material (concrete), resisting the deteriorating force should be durable to resist the attacking force. To this end, the concrete cover (which is the first line of action) [5] and core should be designed to resists surface water as well as permeation of water under pressure.

This work will seek to comparatively investigate the effects of different admixtures on concrete properties such as compressive strength and permeability. The role admixtures play in increasing concrete resistance to agents of deterioration will be brought to the fore. This work will also provide some guidelines to Engineers and designers in selecting admixtures for jobs where compressive strength and permeability pose challenges.

III. MATERIALS

Grade 52.5 Ordinary Portland cement was used. It was manufactured in the United Kingdom by Hanson Heidelberg cement group. It complies with the specifications of BS EN 197-1. It has a density of 3029kg/m^3.

Fine aggregate sand with density of 2670kg/m^3 was used. The particle size distribution in accordance with BS 882: 1992, indicates a well graded fine aggregate as represented in Fig.1.

Coarse Aggregate Gravel from a local supplier, with maximum particle size of 14mm and having a density of 2525kg/m^3 was used. The particle size distribution in accordance with BS 882: 1992, as represented in Fig. 1 indicates a uniform grading.

Clean portable tap water was used. The water was devoid of smell, grease and other impurities.

Four different admixtures were used in conformity with BS EN 934-3: 2009. Their dosages were in compliance with the manufacturer's specification. In cases where there is a range of dosage, the mean dosage was used. The admixtures are:

Waterproofing admixture: Manufactured by the Sika group, United Kingdom. A dosage of 1% by weight of cement was administered according to the manufacturer's specification.

Accelerator: It is a product of Everbuild Building Products Limited, United Kingdom. The specified dosage is 2.5 - 5 litres/50 kg of cement. Hence the mean dose of 3.75 litres/50kg of cement was used.

Sulphonated Naphthalene Formaldehyde Condensates (SNF) Superplasticizer (Conplast SP430): This is a chloride free polymer based admixture manufactured by Fosroc limited, United Kingdom. It complies with BS 5075 part 3 and ASTM C494 as Types A and F. The dosage range is 0.70 to 2.00 litres/100 kg of cement. Hence the mean dose of 1.35 litres/100kg of cement was used.

Polycarboxylate Ether (PCE) Superplasticizer (Auracast.200): Manufactured by Fosroc limited, United Kingdom. The manufacture's dosage range is 0.3 litres to 1.2 litres for every 100 kg of binder content. The mean of this dosage was used, that is, 0.75l /100kg cement.

IV. EXPERIMENTAL PROGRAMME

Five mixes comprising of a control mix and four admixtures: accelerator, waterproofer, two superplasticizers- Sulphonated Naphthalene Formaldehyde condensates (SNF) and a Polycarboxylate Ether (PCE) were used. A concrete grade of 30MPa was designed for as the control mix using the British mix design method as developed by the Department of Environment (DOE 1988). A mix proportion of 1: 1.75: 2.40 with water-cement (w/c) ratio of 0.55 was adopted for the control mix. A very workable slump of 150-180mm was designed for. This is to enhance ease of concrete placement especially in areas of congested reinforcement.

Mixing was done in accordance with BS 5328: part 2:1997. A 50 litre-capacity mechanical rotary mixer was used. Coarse aggregate, cement and fine aggregates were added in that sequence before commencement of mixing. Water and admixtures were then gently added in the course of mixing. The materials are allowed to mix properly until a homogeneous mixture is obtained.

Thereafter, slump test was carried out in accordance with BS EN 12350-2:2009 to determine the workability of the freshly mixed concrete. Appropriate water reduction was carried out in mixes involving admixtures so that the slump is within the designed range.

The fresh concrete is then poured into plastic moulds: 150mm x 150mm x 150mm cubes and 50mm diameter x 100mm high cylinders. These moulds were well greased so as to enable easy de-moulding when the concrete is dry. The fresh concrete is then compacted for a few minutes on a vibrating table. This is done to reduce the amount of air pockets in the concrete.

After 24 hours of setting, the moulds were removed and the samples cured in water tanks by complete immersion. The curing temperature was kept at 22°C ±3°C.

Compressive strength test was carried out in line with BS EN 12390-3-2009 after 3, 7 and 28 days. Three samples were tested for each mix, and their average compressive strength taken.

Also, the Initial Surface Absorption Test (ISAT) is carried out after 28days in line with BS 1881-208:1996. The samples were first removed from the curing tanks and allowed to dry for 24 hours before testing. Care must also be taken to grease and clamp the cap adequately to eliminate leakages which could introduce error in the results. Overall, three samples were tested and the average result taken for each mix to authenticate results.

The HPPT was conducted after 28 days. The apparatus is a slight modification of the Hoek cell. Concrete disc of 50mm diameter by 30mm thickness was cut from the cylindrical concrete specimen. Care must be taken to ensure a smooth cut to avoid rough surfaces that may provide pores for water permeation. Also the applied oil pressure should be least 10Atm higher than the water pressure at all times: this is to ensure that a proper seal is produced around the sample curved surface and hence stop any water from passing around it. The apparatus is switched on, the volume of water and time taken to permeate through the concrete is measured. It is advisable to measure the mass of the water that permeates through the concrete and thereafter convert it to volume. This is because there might be parallax error due to the water meniscus in the measuring cylinder or test tube. Secondly, some of the water may trickle onto the test tube wall thereby introducing error.

Thereafter, Darcy’s law which describes the flow of a fluid through a porous medium is used to calculate the coefficient of permeability as in equation 1 below:

$$Q = \frac{KA\Delta P}{\mu L} \qquad 1$$

Where:
Q= flow rate in (m^3/sec)
K= coefficient of permeability (m^2)
A= Cross sectional area of sample (m^2)
= water pressure difference
μ= Viscosity of water (N.s/m^2)
L= Length of sample

V. RESULTS

The workability as measured by the slump test is the average of two true slump values obtained from the same mix. Results of compressive strength are average values obtained on at least three specimens at each age of testing. ISAT and HPPT tests results are average of three specimens tested in the laboratory after 28days.

Table 1: Results of Water reduction for all Mixes

MIX	ABBREVIATION	WATER REDUCTION (%)	W/C
Control	CON	0	0.55
Control + Waterproofer	WP	5.36	0.52
Control + Accelerator	ACC	18.17	0.45
Control + SNF Superplasticizer	SP1	36.66	0.35
Control + PCE Superplasticizer	SP2	37.59	0.34

Table 2: ISAT Results and Classification in accordance with Concrete Society (1988)

MIX	ISAT VALUES (ml/m^2.s)			Concrete
	10 mins	30 mins	60 mins	Absorption
CON	0.48	0.31	0.2	Average
WP	0.39	0.24	0.18	Average
ACC	0.34	0.19	0.14	Average
SP1	0.11	0.061	0.035	Low
SP2	0.097	0.061	0.035	Low

Table 3: Results and classification of Intrinsic Permeability k in accordance with Concrete Society (1988)

Mix	k Values (m2)	Concrete permeability
CON	4.18×10^{-18}	Average
WP	1.36×10^{-18}	Average
ACC	9.26×10^{-20}	Low
SP1	-	-
SP2	-	-

Fig. 1: Particle size distribution of coarse and fine aggregates

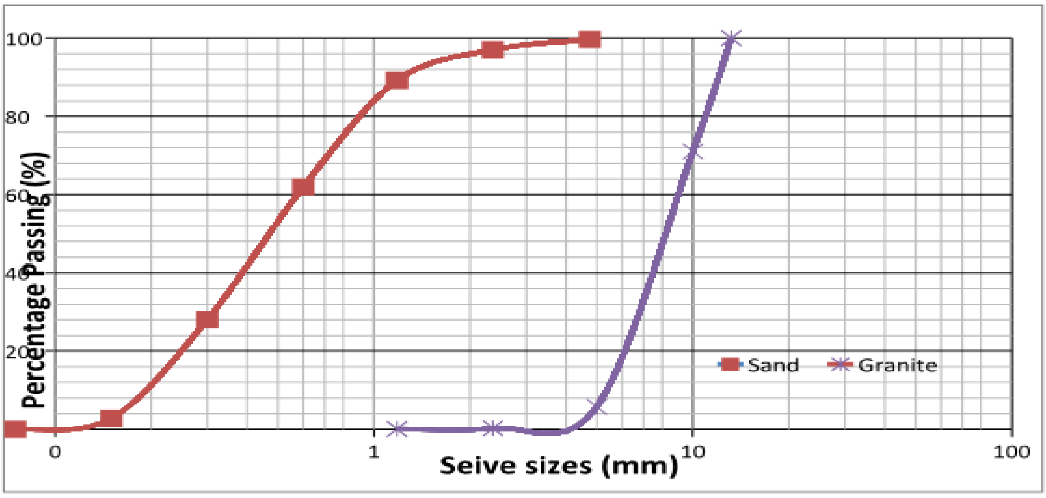


Fig. 2: Graph of compressive strength against curing age

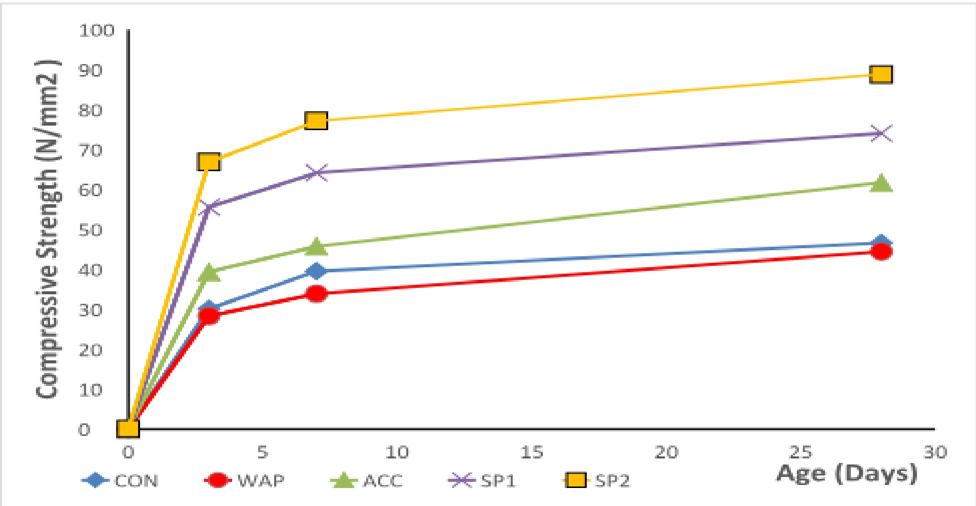


Fig. 3: Histogram of compressive strength against curing age

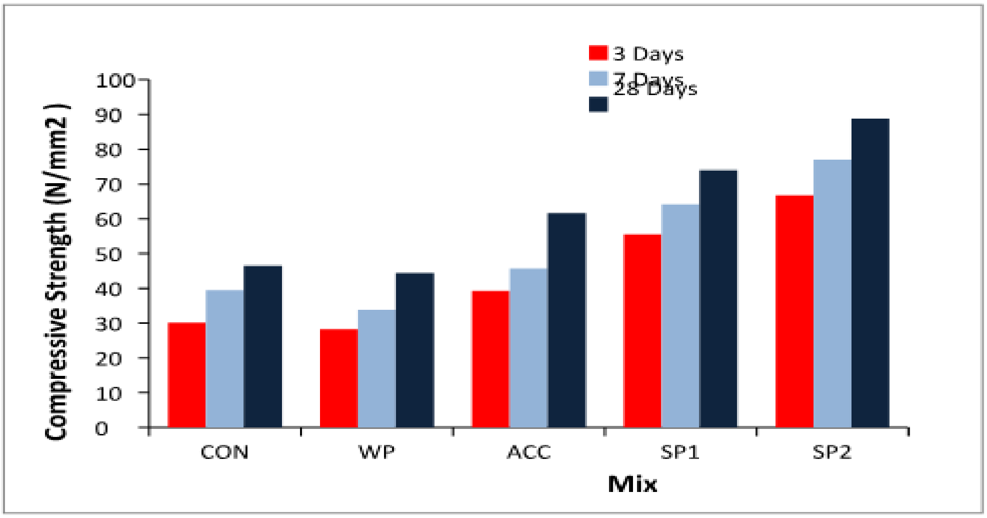


Fig. 4: ISAT values for different mixes

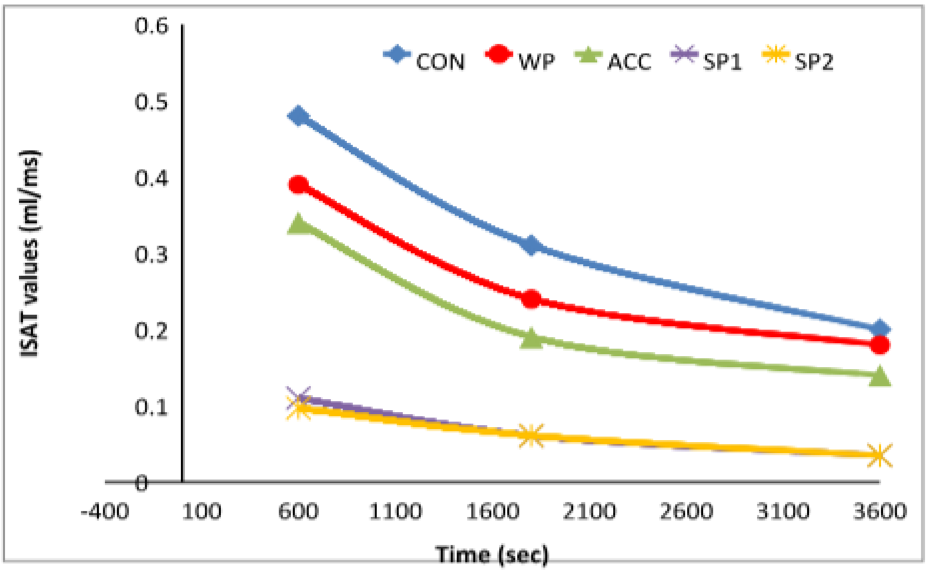


Fig. 5: ISAT values for different mixes

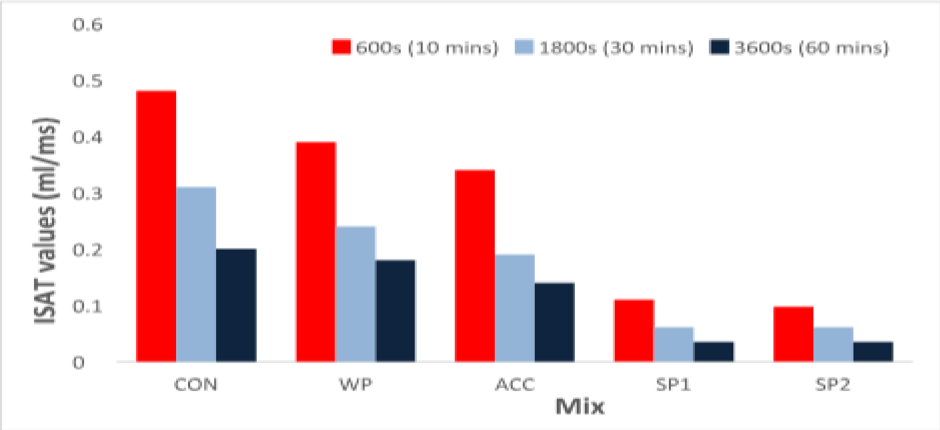
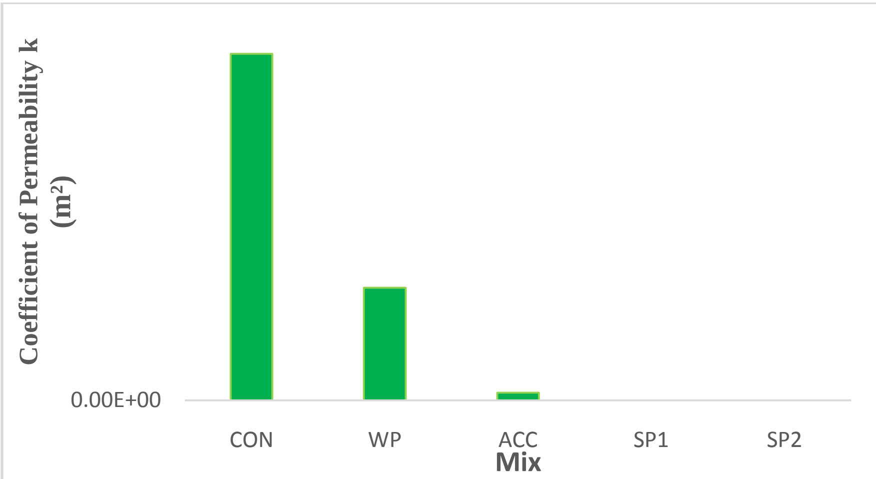


Fig. 6: Histogram of Coefficient of Intrinsic permeability for the various mixes



VI. DISCUSSIONS

6.1 Compressive Strength

The compressive strength result for the various mixes is shown in Fig. 2 and 3.

It was generally observed that the compressive strength of all the mixes increased with increase in age. This can be attributed to continuous hydration of cement and the formation of more Calcium Silicate Hydrate CSH during the curing process.

On introduction of admixtures, the water content had to be reduced to maintain the design slump of 150-180mm (Table 1). This had an attendant effect on their 28day strength. The accelerator had a water reduction of 18.17% and gave a 28day strength of 46.58 N/$mm^2$the SNF superplasticizer (SP1) had a water reduction of 36.66% and gave a strength of 74.01 N/mm^2at 28 days, while the PCE superplasticizer (SP 2) had a water reduction of 37.66% and gave a strength of 88.79 N/mm^2. Similar results were obtained by [11] and [12]while working with superplasticizers. This increase in strength occasioned by reduced w/c may be attributed to the reduction of evaporable water as well as voids that may be occupied by the hydrated CSH products [9]; [13].

On the other hand, the water proofing admixture was found to have strength lower than the control at all ages; this is in spite of its water reduction. This could be attributed to either the increased air entrainment or reduction in rate of cement hydration[14] . Their ability to entrain air, may have given rise to pores within the concrete sample. These pores could be responsible for a reduction in compressive strength.

It was observed that the SNF superplasticizer (SP1) had 58.89% strength higher than the control at 28days while the PCE superplasticizer (SP2) was found to be 90.62% higher in strength compared to the control at 28days. The relatively high strength obtained by the PCE superplasticizer could be attributed to its high ability to deflocculate and disperse cement thereby allowing for greater interaction and thus more hydration reaction between the cement binding material and other concrete constituents[15]. Furthermore, the above explanation also apply to the ability of superplasticizers to produce flowing concrete that can be self-compacted. This may have also contributed to the reduction of voids and hence denser concrete with higher compressive strength.

Results also show that the PCE superplasticizer which is the latest generation superplasticizer, gave a higher water reduction and strength in comparism with the SNF superplasticizer (SP1). This is attributed to the dispersion mechanism of the acrylate groups (polymethacrylic acid) in their backbone and the steric hindrance effect created by a side chain of carboxylate groups (polyethylene oxide) [16]; [17]; [18]; [19]

6.2 Initial Surface Absorption Test ISAT

The results of the ISAT test are presented in Fig. 4 and 5. It can be observed that the rate of absorbtion of all the concrete samples generally decreases with time as water filled length of capillaries increases. Also, all mixes containing admixture gave water absorption lower than the control. This could be attributed to reduction of w/c in these mixes. At lower w/c, the amount of pores and voids in the concrete is reduced, hence absorption is reduced.

Also, the hydrophobic effects of the water proofing admixture may have reduced the amount of water entering the concrete, especially as the concrete is under very little water pressure (200mm head). Furthermore, the reduced surface absorption may be attributed to the discontinuity of capillary as well as size reduction of capillary sizes by the waterproofers[14].

From Table 2, the absorption values of the superplasticizers were generally classified as low. The superplasticizers, in addition to having the least w/c also have a good dispersion ability of cement. Consequently, more cement is readily available for better mixing, hydration and pore blocking. Furthermore, the excellent dispersion improves the self-compacting ability of the concrete with reduced voids. All of these, may have resulted in the very low absorption and permeability observed in the mixes containing he superplasticizers.

6.3 High Pressure Permeability Test HPPT

The results of the HPPT are presented in Table 3 as well as Fig. 6. It was observed that results were only obtained for the control (CON), waterproofing (WP) and accelerator (ACC) mix. Results were not obtained for the two superplasticizers (SP1 and SP2) even when the samples were allowed to stay in the test apparatus for 72 hours and the water pressure maintained at 50 bars.

It was observed that a reduction in w/c due to the effect of the admixtures reduced permeability. Reduced w/c implies a reduction of voids and subsequent occupation of these voids by hardened cement paste thus, lesser values of k.

In spite of the reduced water content achieved by the waterproofer, it is observed that not much difference exists between the k values of the control and the waterproofer. With reference to[20], it can be seen that both mixes have average permeation, whereas, the accelerator has a low permeation. Thus, results obtained show that the waterproofing admixture cannot be regarded as being effective when used in water under pressure. This may be due to the hydrophobic effect of waterproofers been unable to prevent or repel water under pressure [21] and [22]. In addition, their inability to achieve sufficient pore blocking may also be a factor. Furthermore, their ability to entrain air, may have given rise to pores within the concrete sample. These pores could have provided a continuous pathway for the flow of water under pressure[4].

Conversely, the near impermeability of the superplasticizers may be attributed to their higher dispersion ability of cement particles during mixing which facilitates the production of less porous and dense concrete. In addition, the effect of age on reducing concrete permeability through pore blocking and healing as a result of the additional products formed by calcium silicate hydration CSH may have contributed to this result [23] and [24].

VII.CONCLUSION

Based on the experimental results and discussions of this research, the following conclusions can be drawn:

- Admixtures such as accelerators, superplasticizers; Sulphonated Naphthalene Formaldehyde condensates (SNF) and Polycarboxylate Ether (PCE), when combined with a reduction in w/c gave a higher compressive strength, lower surface absorption and lower permeability than reference conventional concrete.

- Waterproofing admixtures, inspite of the reduction in w/c, gave compressive strength less than the control mix. However, it gave lower values of water absorption and lower intrinsic permeability for water under pressure than the reference mix.
- Superplasticizers, particularly the Polycarboxylate Ether (PCE) are the most effective admixtures when compared to waterproofers and accelerators in the production of very high strength and durable concrete.

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Appendix
Appendix A

Table 1. Classification of concrete based on ISAT results (Concrete Society 1988)

ISAT VALUES (ml/m^2.s)			Concrete
10 mins	**30 mins**	**60 mins**	**Absorption**
> 0.50	> 0.35	> 0.20	High
0.25 - 0.50	0.17 - 0.35	0.10 - 0.20	Average
< 0.25	< 0.17	< 0.10	Low

Table 2 Classification intrinsic permeability of concrete (Concrete Society 1988)

Method	Concrete Permeability		
	Low	**Average**	**High**
Intrinsic permeability k (m^2)	<10^{-19}	10^{-19}- 10^{-17}	>10^{-17}