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AN INVESTIGATION OF THE BEHAVIOUR OF BINARY AND TERNARY BLENDS OF BINDING MATERIALS IN CONCRETE

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Abstract: This research investigated the influence of introducing binary and ternary blends of binding materials on the properties of concrete. Calcium hydroxide is one of the hydration products of cement which creates a weak link in concrete, thereby affecting the durability properties of the concrete. Supplementary Cementitious Materials have been known to react with the deleterious calcium hydroxide to create additional beneficial Calcium Silicate Hydrate, which is the main cementing component in concrete. Supplementary Cementitious Materials reduce the quantity of lime and increase the quantity of the Calcium Silicate Hydrate. The cementing quality is enhanced if a good pozzolanic material is blended in suitable quantity with Portland cement. A standard mix proportion of 1:2:4 and water cement ratio of 0.65 was adopted for all the concrete mixes. A total of 36 cubes of 150mm x 150mm x 150mm were cast with 20% OPC/AHA and 10% OPC/CCA binary blended cement concrete, 36 with OPC/AHA/CCA ternary blended cement concrete at percentage OPC replacement of 5%, 10%, and 15% were crushed to obtain the compressive strengths at 7, 21, 28, and 56 days of curing, 18 beams were also produced and tested for flexural strength. The 7 – 21 day compressive strength of 20% OPC/AHA binary blended concrete were found to be much higher than the control values; the compressive strength for 28 -56 days were slightly lower than the control values. The 10% OPC/CCA attained the highest compressive strength of 24.50N/mm2 at 56 days of curing. The 56 day compressive strengths obtained from the ternary blended cement concrete with equal quantities of AHA and CCA were 25.60 N/mm2 for 5% replacement, 19.50 N/mm2 for 10% replacement, 17.00 N/mm2 for 15% replacement while the value for the control was 26.80 N/mm2. The increase in 56 day strength as compared to the 28 day strength is an indication of pozzolanic activity by the blended concretes. The flexural strengths for the ternary blended cement concrete at 5% replacement were comparable to the values of the control and higher than those of the binary blends. Based on the results of the research, thus, OPC/AHA/CCA ternary blended cement concrete could be used where light weight material is required and for construction works where early strength is not necessarily a requirement.

Key words: Acha Husk Ash (AHA), Corn Cob Ash (CCA), Blended Cements, Binary Blends, Ternary Blends.

I. INTRODUCTION

Cement is a fine-grained compound that sets and hardens in the presence of water to bind other materials such as sand and, or coarse aggregates to form mortar or concrete. Cements used in construction can be characterized as being either hydraulic or non-hydraulic, depending upon the ability of the cement to be used in the presence of water (Neville, 2011).

Before the advent of modern cement many binders were in use, the Romans used pozzolana cement from Pozzouli, Italy near Mt. Vesuvius to build many famous Roman structures; they used broken bricks and stone aggregates embedded in a mixture of lime putty with brick dust or volcanic ash by the Romans (Neville, 2011). A pozzolan is a siliceous or siliceous aluminous material which in itself, possesses little or no cementing property, but will in a finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (Neville, 2011).
Cement is the most commonly used building material in the world, especially in developing countries, and is widely produced and utilized throughout the world (Ohimain, 2014). Cement is widely noted to be the most expensive constituent of concrete and its high cost has been due to both the limited raw materials and the industrial processes undergone by the cement during the manufacturing stage (Sumaila and Job, 1999). Cement production processes releases a large quantity of CO_2 into the atmosphere, which results in environmental problems of degradation (Oluremi, 1990). Goh and Nwankwo (2011) stated that $Ca(OH)_2$ produced from the hydration of cement creates a weak link in concrete due to its solubility in water.

To address some of the afore mentioned issues of cost of concrete, environmental degradation, deleterious $Ca(OH)_2$, researchers have conducted studies on other binding agents with lower cost of production to either partially or totally replace the cement which is the conventional binder in concrete. Bakar, Putrajaya, and Abdulaziz (2010) reported that supplementary cementitious materials have proven to be effective in meeting most of the requirements of durable concrete. In the third world, the most common and readily available materials that can be used to partially replace cement without huge economic implications are agro – based wastes

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(Akhionbare, 2013). Goh and Nwankwo (2011) reported a reduction in Ca $(OH)_2$ content in concrete with the replacement of cement with a ternary blend of Fly Ash and Calcined Waste crushed Clay Bricks.

Pozzolana in a finely divided state combines with calcium hydroxide (produced by the hydrating Portland cement) in the presence of water to form stable calcium silicates which have cementitious properties (Neville, 2011). Mehta (1987) opined that pozzolanas are natural or artificial materials containing silica or/and alumina in a reactive form. The natural pozzolanic materials include: volcanic ash, pumice, opaline shale and chert, calcined diatomaceous earth, and burnt clay (Neville, 2011). Artificial pozzolanas of organic origin include; most agricultural waste such as; rice husk, coconut shell, corn cob, palm nutshell fiber and Acha husk among many others.

Investigation into the use of several of these as pozzolans have been conducted, and some of the products that have shown pozzolanic properties include; Acha Husk Ash (AHA), Dashan and Kamang (1999), Saw Dust Ash (SDA), Sumaila and Job (1999)), Rice Husk Ash (RHA), Chungsangunsit et al (2009), Palm Fruit Ash, Olonode (2010), and Corn Cob Ash, Adesanya and Raheem (2009), Groundnut Husk Ash, Elinwa and Awari (2001). Cements with partial replacements of pozzolans are referred to as blended cements, these are Cement mixtures containing Ordinary Portland cement (OPC) and at least one or more supplementary cementitious materials (SCMs). They are basically divided into binary and ternary blends, binary cements contain Ordinary Portland Cement (OPC) and one Supplementary Cementing Material (SCM), whereas ternary blends contain OPC and two SCM.

Khatib and Hibbert (2005) conducted test on strength gain using Portland cement, Ground Granulated Blast Furnace Slag (GGBFS) and metakaolin; the test indicated that ternary blended cements maintained the benefits of their binary components while overcoming any shortcomings of the binary blend. Also Ghrici, Kenai, and Mansour (2007) carried out test on limestone, Portland cement and a natural pozzolana, the results showed that early age and long term compressive and flexural strengths of the ternary blend were better than the control mixes. Murthi, and Siva (2009) studied the relationship of Compressive Strength and splitting tensile strength of Ternary Blended Concrete. The Ternary Blended Concrete was developed by replacing the cement content in a binary system using Micro Silica (MS). The replacement of cement in the binary system by Micro Silica was suggested as 4%, 8% and 12% of total powder content by weight.

II. MATERIALS AND METHOD

The cement used for this study is the Nigerian brand of Ordinary Portland Cement. Natural river bed quartzite sand obtained for the test was air dried, sieved and falls within zone 2 based on the classification of BS 882: 1973. The particle size distribution are presented in table 1, the specific gravity of the sand used for the test was found to be 2.62. The coarse aggregates used were machine crushed granite of maximum size of 20mm obtained from a quarry in Jos.
The Acha Husk and the Corn Cob collected were air dried in preparation for burning inside an electric furnace at temperatures of 650 -700^0 C for two hours. The chemical properties of the AHA and CCA and the loss on ignition were determined after burning of the two samples.

A mix proportion of 1:2:4 with a water cement ratio of 0.65 was adopted to achieve the required strength. The OPC was blended with 20% optimum AHA replacement as recommended by Dashan and Kamang (1999), 10% CCA (Olafusi and Olutoge, 2012) and then in the range of 5 - 15% for the ternary blends of OPC/AHA/CCA.

The constituents of each of the different mix were manually mixed on a non-absorbent platform, the OPC and the different replacement constituents were evenly spread on already measured sand and thoroughly mixed before adding the measured coarse aggregates and water. The constituents were mixed until the right consistency was obtained.

The moulds for the test were 150mm x 150mm x 150mm metal cubes and thoroughly cleaned and oiled to ensure a smooth finish and for easy de-moulding. The casting was done in accordance to the requirements of BS EN 12390-3, (2000) for compressive test, and BS-EN-12390-5:2000, BS-EN-12390-1:2000 for flexural test. All cubes were de-moulded after 24 hours and then cured in water for 7, 21, 28, and 56 days.

III. RESULTS AND DISCUSSION

Chemical Composition and Physical Properties

The chemical composition of the pozzolans are given in tables 2 and 3. The results of the analysis of the of the AHA as shown in table 2 that sum of the oxides of silica, aluminium and iron present in the ash was 60.86%. This is higher than the 40.46 reported by Dashan and Kamang (1999) and less than the 62.98% reported by Tok and Nensok (2011). The value obtained was also less than the 70% minimum requirement for pozzolanas as reported by Neville, 2011. The loss on ignition was 24.66, which is less than the 24.78

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reported by Tok and Nensok (2011) and this value is more than the 12% maximum requirement for pozzolanas. This implies that the Acha husk Ash contains un burnt carbon which reduces the pozzolanic activity of the Ash. The bulk density of AHA as revealed by the test was 722kg/m^3, which is close to the results reported by Dashan and kamang (1990), 740 kg/m^3 and the 726 kg/m^3 reported by Tok and Nensok (2011). The specific gravity was also determined to be 2.11 which is close to the 2.10 reported by Dashan and Kamang (1999), and 2.10 recorded by Tok and Nensok (2011).

Table 3 shows the result of the Chemical analysis of the CCA. The sum of the oxides of silica, aluminium and iron present in the ash was 81.28%. This is lower than the 83.03% reported by Oluborode and Olufuntuyi (2015) and higher than the 81.09% reported by Mujedu, Adebara and lamidi (2014). The value obtained is higher than the 70% minimum requirement for pozzolanas as specified by ASTM C 18-78, 1978. The loss on ignition was also found to be 8.66, the bulk density of CCA as revealed by the test was 805kg/m^3. The results show that the material is a light weight material. The specific gravity determined for CCA was 2.26 which is lower than the 2.27 recorded by Oluborode and Olofintuyi (2015), but higher than the 1.90 reported by Ettu, Anya, Arimanwa, Anyaogu, and Nwachukwu, (2013).

Slump Value of Concrete

Table 4 shows that the slump values decreases with increase in percentage of AHA/CCA replacement in concrete. From the result, it was observed that the concrete became less workable as the percentage of AHA/CCA increases, meaning that more water will be required to make the mix more workable. The high demand for water as AHA/CCA increases is due to the increased amount of silica in the mixture, this is a typical pozzolan behaviour in cement concrete in which the silica - lime reaction would require more water in addition to the water required for hydration of cement (Adesanya and Raheem, 2009).

Variation of Density with hydration Periods

Figure 1 is the variation of density of cubes with curing period, the results show a general increase in density as the curing age increases but however, decreases with increase in percentage replacement of AHA/CCA. The control produced the highest density of 2640 kg/m^3 at 28 days and generally increased from 2550 kg/m^3 at 7days to 2680 kg/m^3 at 56days. AHA/CCA at 5% replacement showed an increase of 2520 kg/m^3 at 7days to 2600 kg/m^3 at 56days, 10% replacement produced 2470 kg/m^3 to 2520 kg/m^3, and 15% showed 2380 kg/m^3 to 2440 kg/m^3 in the same hydration period.

Table 5 is the variation of density of concrete beams at 28 days curing age. The results show a general decrease in density with increasing percentage replacement of AHA/CCA. The 0% control produced the highest density of 12370 kg/m^3 at 28 days, followed by 10% CCA binary blend at 12360 kg/m^3, and 5% Ternary AHA/CCA concrete at 12060 kg/m^3, 10% Ternary AHA/CCA concrete at 12020 kg/m^3, 15% Ternary AHA/CCA concrete at 12000 kg/m^3, while 20% AHA binary blend produced the lowest density of 11880 kg/m^3.

Compressive Strength

Figure 2 shows the relationship between compressive strength development and hydration periods of 7, 21, 28, and 56days at 20% replacement of AHA. The results show an increase in strength from 7 – 21 days but a decrease in strength from 28 -56 days, which is indicative of a deterioration of the concrete. It was observed that the maximum strength of 26.50N/mm^2 was attained after 21 days of curing with the replacement of OPC with 20% AHA. There was however, a reduction in compressive strength after 28 days of curing. These results agree with the previous works of Dashan and Kamang, (1999). The addition of AHA to Concrete increased its initial strength at the early days of hydration, but subsequently there is a decrease in strength as the hydration day's increase.

Figure 3 revealed an increase in compressive strength of OPC/CCA concrete as the curing age increases. The Maximum strength of 23.80N/mm^2 was attained at the curing age of 28 days which is lower than the 25.65 N/mm^2 of the control. This value is however, higher than the value of 20.00N/mm^2 reported by Olafusi and Otuge (2012) at 28 days. The strength developed though lower than the control, but is 93% of it, and therefore close enough to be acceptable for concrete works.

Figure 4 shows the strength development for various replacement levels of the ternary blend of OPC/AHA/CCA in concrete. The figure shows a general increase in strength with curing age and a decrease as the percentage of CCA and AHA increases. The results show that ternary blends of OPC/AHA/CCA develop strength slowly at early curing days, which agree with previous works of (Oluborode and Olufintuyi, 2015, Adesanya and Raheem, 2009, Mujedu et al, 2014). All the other preceding curing days indicated a continuous increase in strength for all percentage replacement levels of ternary blend. The ternary blend of OPC/AHA/CCA produced the highest strength of 24.60 N/mm^2 at 5% replacement at 28 days. The results at 56 days showed that the pozzolanic action has started as can be seen in the increased in compressive strength development by the OPC/AHA/CCA concrete. The strength gain can be attributed to the cementatious products formed as a result of hydration of cement and those formed when lime reacts with the pozzolan in corporated in the concrete mix (Mujedu et al, 2014).

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Flexural Strength

Table 6, shows the results of the flexural strength test of the binary blend of OPC/AHA at 28 days of curing in water. The results show that the behaviour pattern of flexural strength follows that of the compressive strength. The flexural strength of the mix is 17% of the values of the compressive strength which is in agreement with the assertion of between 10 and 30% by Neville (2011).

Table 7 shows the results of the flexural strength test of the binary blend of OPC/CCA at 28 days of curing in water. The results show that the behaviour pattern of flexural strength follows that of the compressive strength. The flexural strength of the mix is 17% of the values of the compressive strength which is in agreement with the assertion of between 10 and 30% by Neville (2011).

Table 8 shows the results of the flexural strength of ternary blends of OPC/AHA/CCA at 28 days of curing in water. The results show that the behaviour pattern of flexural strength follows that of the compressive strength. The flexural strength of the 5% replacement which is the optimum ternary replacement level of the mix is 28% of the values of the compressive strength which is in agreement with the assertion of between 10 and 30% by Neville (2011).

IV. CONCLUSION AND RECOMMENDATION

The ternary blend of 5% developed a strength of 24.60N/mm^2 at 28 days which is 96% of the control, and also higher than the highest strengths developed by the binary blends of OPC/AHA and OPC/CCA respectively. The flexural strengths for the ternary blend at 5% are comparable to the control and higher than those of the binary blends. The concrete produced from the ternary blend has a lower density than the control and could be used as a light weight concrete.

Based on the results of the research and the conclusions drawn, the following recommendations are made; the ternary blend of OPC/AHA/CCA could be used for reinforced concrete works and is especially important where light weight material is needed.

SIEVE ANALYSIS

Table 1: Sieve Analysis for Fine aggregates

Sieve size (mm)	Weight Retained (g)	Cumulative weight retained (g)	Cumulative % retained	Cumulative % passing
4.74	-	0	0	100
2.36	12	12	2.4	97.6
1.18	82	94	18.8	81.2
0.60	124	218	43.6	56.4
0.15	282	500	97.4	2.6
Pan	-	-	-	-

Table 2: Chemical Composition of Acha Husk Ash

Oxide	Composition
SIO_2	53.76
Fe_2O_3	4.35
Al_2O_3	2.75
Cao	5.25
MgO	1.01
SO_3	0.00
K_2O	0.23
Na_2o_3	0.21

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Table 3: Chemical Composition of Corn Cob Ash

Oxide	Composition
SIO_2	55.80
Fe_2O_3	10.01
Al_2O_3	15.47
Cao	10.77
MgO	0.88
SO_3	0.65
K_2O	1.78
Na_2o_3	1.90

Table 4: Slump Value of Concrete

% Combination of AHA/CCA Replacement		0	5	10	15	20
Slump (mm) AHA		-	-	-	-	22
CCA	-	-	27	-	-	
AHA/CCA		28	27	25	24	-

Table 5: Variation of Density of Concrete Beams at 28 days (kg/m^3)

w/c ratio	Ash content	AHA/CCA	AHA	CCA)
0.65	0%	12370	-	-
	5%	12060	-	-
	10%	12020	-	12360
	15%	12000	-	-
	20%	-	11880	-

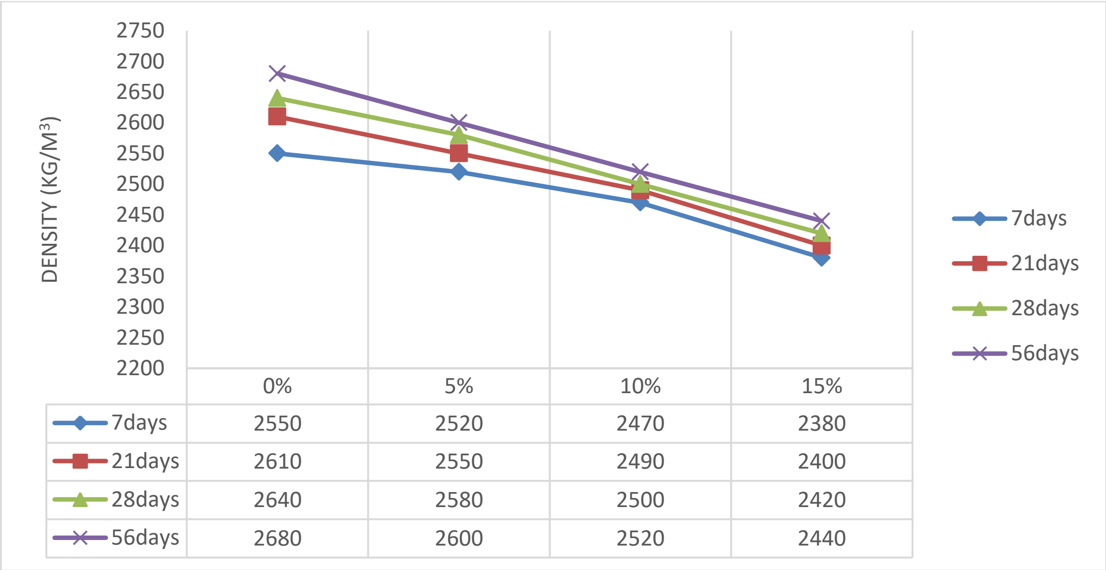

Figure 1: Variation of Density with hydration Periods of Cubes

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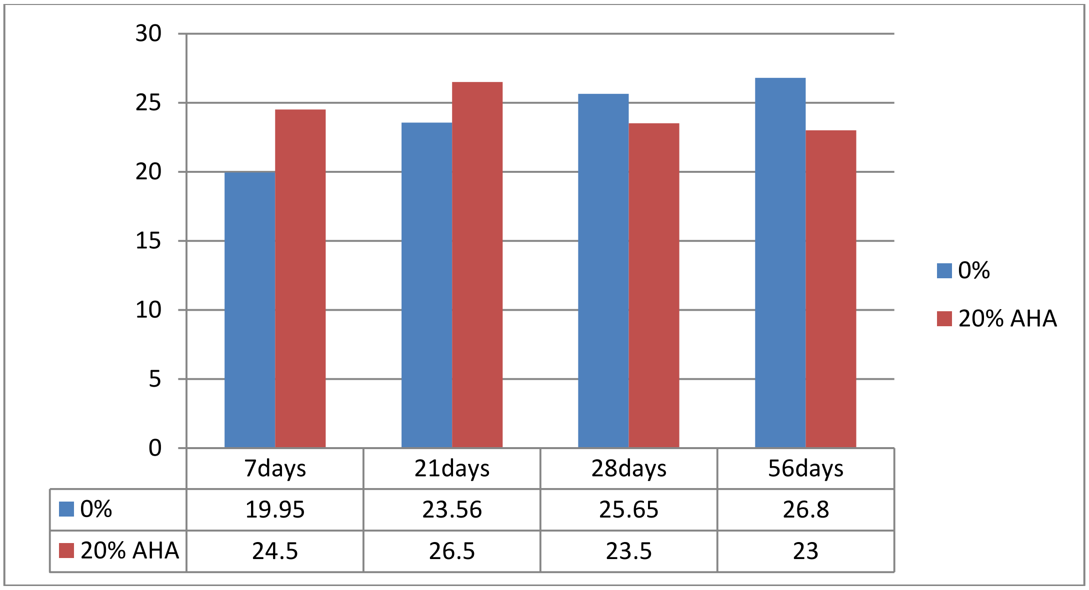

Figure 2: Variation of Compressive Strength of Binary Blend of OPC/AHA with Curing days

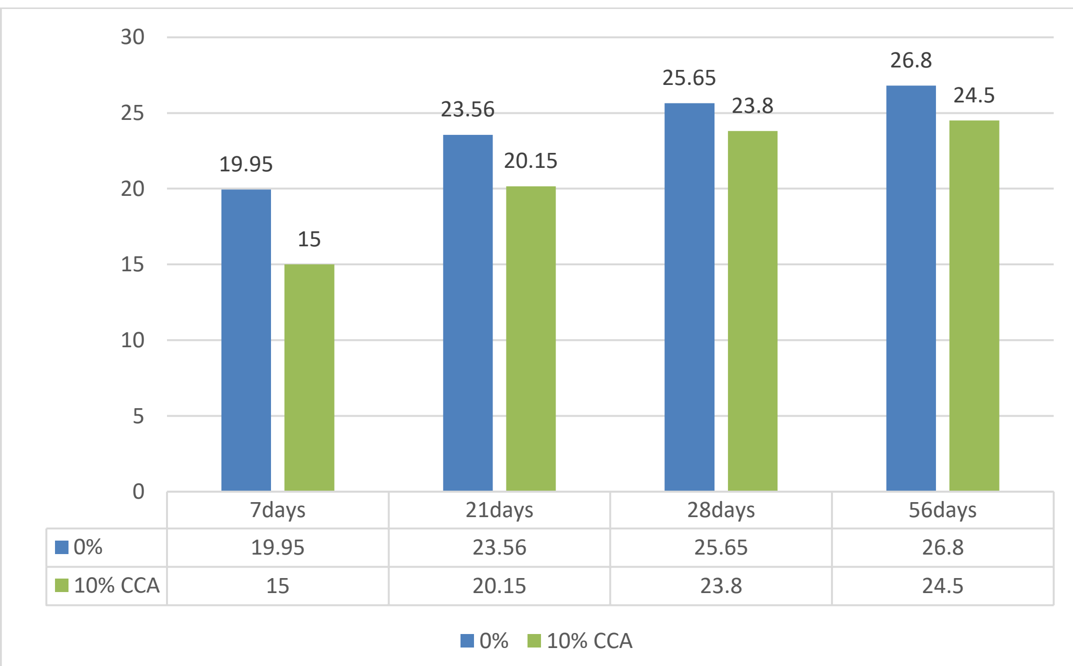

Figure 3: Variation of Compressive Strength of Binary Blend of OPC/CCA with Curing days

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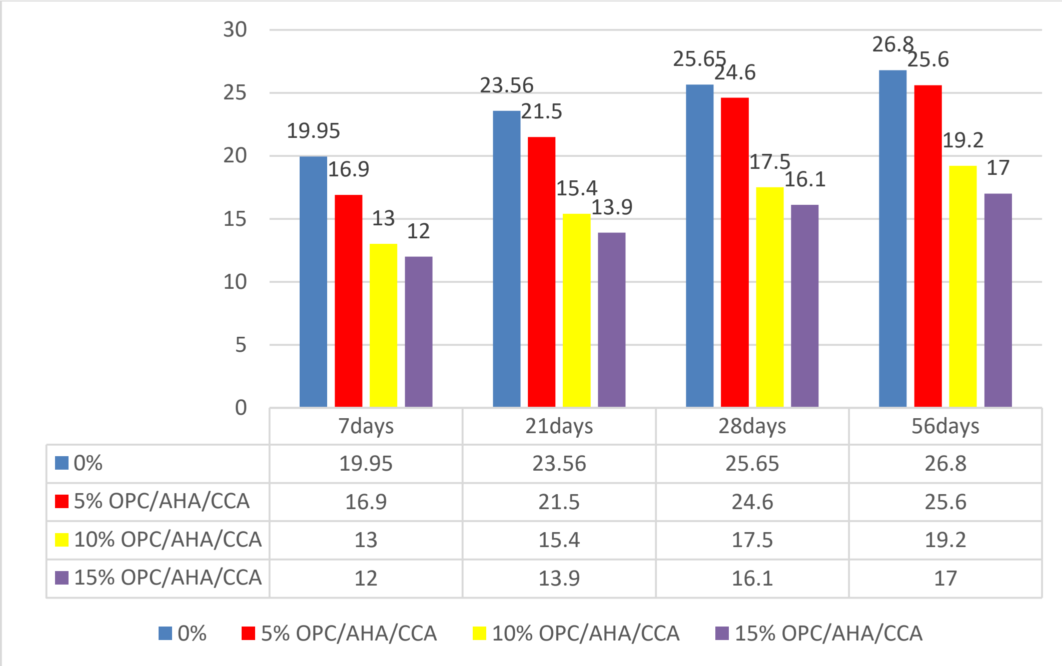

Figure 4: Variation of Compressive Strength (N/mm^2) with Curing days

Table 6: Flexural Strength of Beams of Binary Blend of OPC/AHA

W/C ratio	AHA/OPC Content	Average Flexural strength (N/mm^2)
		28days
0.65	0%	6.0
	20%	4.0

Table 7: Flexural Strength of Beams of Binary Blend of OPC/CCA

w/c ratio	CCA/OPC content	Average Flexural strength (N/mm^2)
		28days
0.65	0%	6.0
	10%	4.0

Table 8: Flexural Strength of Beams of Ternary Blend of OPC/AHA/CCA

W/C ratio	AHA/CCA/OPC	Average Flexural strength (N/mm^2)
0.65	Content	28 days
	0%	6.0
	5%	6.0
	10%	5.0
	15%	6.0

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