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Assessing the Mechanical Performance of Ternary Blended Cement Concrete Incorporating Periwinkle Shell and Bamboo Leaf Ashes

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Abstract

The study investigates the mechanical properties of concrete incorporating Periwinkle Shell Ash (PSA) and Bamboo Leaf Ash (BLA) as cementitious binders. Concrete cube (100mm) prepared from a standardized prescribed mix of 1:2:4, batch by volume was taken as the reference mix. The cement component in the reference mix was replaced with combined % weight of periwinkle shell ash (10-30%) and bamboo leaf ash (10% fixed) given five blended mixes. Water-cement ratio of 0.60 was adopted for the reference and blended mixes. A total of 144 cube specimens were evaluated for compressive and tensile splitting strength at four curing ages up to 56 days. The results indicated that the compressive strength generally increases with curing age, and that the mix containing 80% cement-10%PSA-10%BLA, outperformed that of the reference mix at 28 and 56 days. The tensile splitting strength increase with curing age and decreases as the % weight of PSA increases from 15% to 30%. A higher tensile splitting strength value was attained with mix 2 than the reference mix at 14, 28 and 56 days. The regression equation for the strengths relationship was obtained as $F_{SP} = 0.141 (F_{cu})^{0.873}$. The study concluded that mix 2 proportion is adequate for the production of ordinary structural mix concrete.

Keywords: periwinkle shell ash, bamboo leaf ash, blended cement concrete, compressive strength, tensile Splitting strength

1. Introduction

Concrete, which basic ingredient is cement, is one of the most versatile construction materials widely used. The annual global production of Portland cement concrete as reported by Mehta and Monteiro (2006) is about 11 billion metric tonnes. However, the production of Portland cement, an essential constituent of concrete, leads to the release of hazardous gasses such as CO_2, NH_4 and NO_X into the atmosphere which contributes to global warming. For instance, it has been reported that over 90% of carbon emissions from the concrete industry are attributable to Portland cement clinker production in cement kilns, and that approximately 1 tonne of CO_2 is generated for making 1 tonne of clinker (Malhotra, 2004).

Over the years, researchers have investigated into the used of by-industrial wastes and other wastes as components that could be blended with cement clinker without compromising the quality of the cement produced, or partially replaced the cement during batching in concrete production. This approach will leads to development of sustainable infrastructure that is cost effective, environmentally friendly and durable. The materials could be binary, ternary or quaternary blended. The terms binary, ternary or quaternary are used to describe the number of binders to be blended. Binary blended cements contain Portland cement and one supplementary cementing material (SCM); ternary blended cements contain Portland cement and two SCMs, whereas quaternary blended cement has more than two SMCs blended with Portland cement. By implication therefore, ternary concrete mixtures include three different cementitious materials.

It is now possible to replace 50 to 70% Portland cement with one or several supplementary cementing materials, such as coal fly ash, granulated blast furnace slag, natural Pozzolans, silica fume and rice husk ash to produce blended cement concrete, with dramatic improvements in the properties of the concrete.

Ternary blended concrete has the advantages of high strength, low permeability, elimination of thermal cracking and resistance to sulphate, corrosion and alkali-silica reaction. Other advantages include improved workability, reduction in the energy used in cement production, reduction in greenhouse gasses emissions, increased production capacity, and recycling of SCMs (Malhotra, 2004; Worrel and Galtisky, 2004). In addition, ternary blended cement system could potentially be used in the concrete construction industry in lowering down the volume of Portland cement used. The use of ternary mixtures of Portland cement, silica fumes and fly ash as reported by Isaia (1997) led to the improvement in the microstructure and performance of concrete. Mullick (2007) reported that when both silica fume and fly ash are used, the resultant enhancement of strength was greater than superposition of contributions of each, for the respective proportions; and that such synergic effect results from strengthening the weak transition zone in aggregate-cement interface, as well as segmentation and blocking of pores.

Further researches have revealed that some agro-waste materials such as bamboo leaf ash (BLA) (Singh et al., 2007), periwinkle shell ash (PSA) (Umoh and Olusola, 2012; Olusola and Umoh, 2012), corn cob ash (Adesanya and Raheem, 2009), palm oil fuel ash (Tangchirapat, et al., 2009) and sugarcane baggesse ash (Morales et al., 2009) have the prospects of being used as additives or mineral admixtures in cement, mortar or concrete. Accordingly, Chindaprasirt et al. (2008) stated that mineral admixtures from agricultural waste are receiving more attention now since their uses generally improve the properties of the blended cement concrete, and reduce the environmental problems.

Two commonly available agricultural waste materials in the Niger delta of Nigeria, which could be utilized in the ternary blended system, are the periwinkle shell ash and bamboo leaf ash. Periwinkle shell ash is obtained from the burning of periwinkle shells which is a by-product of periwinkle. Periwinkle is one of the seashell foods that are mostly found in waters of the Niger delta region of Nigeria. The shells are usually thrown away after removing the edible periwinkle. The PSA in binary blended system in concrete have been reported to enhance concrete strength and durability with replacement level up to 10% (Dahunsi and Bamisaye, 2002; umoh and Olusola, 2012; Olusola and Umoh, 2012).

Bamboo leaf ash is gotten from the burning of dry leaves of bamboo. Bamboo is a natural fibre that is widely available in Nigeria. It grows in natural vegetation among thick forest and in riverine areas of Nigeria. It is reported that out of 1250 species of bamboo around the world, seven species are found in Nigeria of which the specie *bambusa vulgaris* constitutes 80% (Omotoso, 1983).

In this study, periwinkle shell and bamboo leaf ashes are used as cement supplements with a view to ascertaining the optimum replacement level that will enhance the strength performance in the ternary blended cement concrete.

2. Materials and Method

2.1 Materials

The materials used were Portland cement (PC) produced by ‘UNICEM’ (Nig.) Ltd., Calabar, Cross river state, to the specification of Nigeria Industrial Standard (NIS) 444-1:2003 and coded CEM II/B-L 32.5R which is equivalent to European BS EN 197-1:2009 specification; fine aggregate belong to zone 2, while coarse aggregate (granite chipping) was predominantly of size 14mm, the materials were source from Uyo, Akwa Ibom State. Periwinkle shells were collected from a dump site along Uruan road, about one kilometre from the University of Uyo permanent site; the shells were spread in an open space in the laboratory for 7-8 days. The bamboo leaves were obtained from a nearby bush in the campus and taken to the laboratory where they were spread in an open space for 12-14 days. The periwinkle shells and dried bamboo leaves were calcined, each material separately, in a furnace to a temperature of 600 degree Celsius for 20 minutes. The ashes obtained were found to contain up to 55% calcium oxide in the PSA and over 70% silica oxide in the BLA. The specific gravity of the PSA and BLA were 2.08 and 1.72, respectively.

2.2 Mix proportions

A mixture of 1:2:4 mix ratio representing cement: fine aggregate: coarse aggregate was used as the reference mix. The cement constituent was subsequently replaced with percentage combination of periwinkle shell ash and bamboo leaf ash (by mass). The percentage of the PSA was varied between 10% and 30%, at 5% intervals, with the BLA content kept constant at 10%, which gives a total of six mixes. In each mix, water cementitious materials ratio was fixed at 0.65 and the fine and coarse aggregate kept constant. The various combinations are as presented in Table 1.

2.3 Mixing of Constituent Materials

The cement, PSA, and BLA were measured and mixed together until a uniform colour was obtained. The blended mix was spread on already measured fine aggregate placed on an impermeable flat form and mixed thoroughly before the coarse aggregate and water were added. Workability test was conducted on the fresh concrete with the aid of slump cone apparatus and the value obtained range between 0-25mm.

2.4 casting and curing of specimens

The specimens were cast in well lubricated 100mm cube moulds. A total of 144 cube specimens were cast for the study. After casting they were covered with wet woolen bags and stored in a place not exposed to direct sunlight for a day; de-moulded and immersed in water curing tanks until their testing ages.

2.5 Testing and evaluation of concrete cube specimens

The concrete specimens were tested for compressive strength and tensile splitting strength in a compression testing machine of capacity 2000KN at ages of 7, 14, 28 and 56 days in accordance with BS EN 12390-3 (2009) and BS EN 12390-6 (2009), respectively. Seventy two (72) specimens were tested for compressive strength and 72 for tensile splitting strength. Three specimens were used in computing the mean on each testing age of each mix; and the compressive strength, F_{cu}, estimated thus:

$$F_{cu} = \frac{P}{A} \qquad (1)$$

Where p = magnitude of the load that causes breaking (expressed in Newton), A = cross sectional area of cube (mm^2); and the tensile splitting strength, F_{sp}, estimated thus:

$$F_{sp} = \frac{2P}{\pi A^2} \qquad (2)$$

Where p = maximum load causing splitting of the cube, and A = the side of the cube

3. Results and Discussion

3.1 Compressive strength of ternary blended cement concrete

The compressive strength for the mixes as shown in Figure 1 generally indicated an increase in strength with curing age. In Table 2, the compressive strength decreases as the percentage of PSA content increases from 0% to 30% at constant 10% BLA. The compressive strength at 7 days range between 10.38N/mm^2 and 17.00N/mm^2 for mixes 6 and 1 respectively. It is observed that mixes 2 and 3 attained over 75% of the reference mix (i.e. mix 1).

At 14 days hydration period, the compressive strength for mix 2 increased to 18.07N/mm^2 representing 91.71% of the reference mix followed by mixes 3, 4 and 5 with compressive strength of 15.47N/mm^{2,} 15.00N/mm^2 and 14.82N/mm^2 representing 78.51%, 76.14% and 75.47% respectively and mix 6 attained 10.60N/mm^2 representing 53.81% of the reference mix.

The strength at 28 days increases to 22.40N/mm^2, 23.43N/mm^2, and 19.42N/mm^2 for mixes 1, 2 and 3 respectively. It is also noted that mixes 2 and 3 attained strength of 104.61% and 86.68% of the reference value, respectively. This revealed that mix 2 containing a cementitious combination of 80%PC-10%PSA-10%BLA can contribute to higher strength development at 28 days than the use of 100%PC as the only binder; and also that mix 3 having attained 86.68% of the strength of the reference mix, and which is over 75% as stipulated by ASTMC 618 (2008) for pozzolanic materials replacement in cement, can be considered an optimal mix combination for use in mass concrete.

At 56 days, mix 2 outperformed that of the reference mix with a value of 109.58%; followed by mix 3 which attained 86.89% of the reference mix, while mixes 4-6 had compressive strength values ranging from 15.10N/mm^2 to 16.17N/mm^2 representing 64.89% and 69.47% which is less than 75% of the reference mix.

3.2 Tensile splitting strength of ternary blended cement concrete

Concrete is not normally designed to carry load in tension, hence its tensile strength is generally considered as a negligible parameter. However, the knowledge of tensile strength as stated by Abdul Razak and Wong (2004) is of substantial importance in concrete structures particularly with regards to crack mitigation. For serviceability Limit states, tensile strength is often a more important parameter than compressive strength.

The results of the tensile splitting strength as shown in Figure 2 indicate that the tensile splitting strength increases with increased in curing age and decreases as the percentage of the PSA increases from 15% to 30%. The values of the strength range between 1.71N/mm^2 and 1.05N/mm^2 for mix 1 and 6 at the curing age of 7 days (Table 3).

At 14 days, it was observed that mix 2 recorded the highest value representing 101.74% of the reference mix. Further increase in strength was noted at 28 days hydration with mix 2 leading with 2.19N/mm^2, and apart from mix 6, other mixes attained over 75% of the reference mix.

At 56 days, the tensile splitting strength increases to 2.15N/mm^2, 2.44N/mm^2, 1.90N/mm^2, 1.72N/mm^2, 1.62N/mm^2 and 1.22N/mm^2 for mix 1 – 6 in that order.
It is observed that mix 2 containing 80%PC-10%PSA-10%BLA preformed better than other mixes, therefore it can be inferred that mix 2 contribute to the improvement of tensile splitting strength than others.

3.3 Relationship between tensile splitting and compressive strength of ternary blended Cement concrete

The strength of concrete is the property most valued from the design point of view and for quality control. Since the compressive strength of concrete is generally accepted as a major index of a concrete strength, there exist relationship between the compressive strength and other strength types such as tensile, flexural, and shear. However, it has been observed that the relationship among various types of strength is influenced by factors like the methods by which the tensile strength is measured (i.e. direct tension test, splitting test, or flexure etc.), the grade or quality of concrete (i.e. low-, moderate-, or high-strength), the characteristics of the aggregate (e.g. surface texture and mineralogy), and admixtures (e.g. chemical admixtures, mineral admixtures or air-entraining) (Mehta and Monteiro, 2006).

The compressive and tensile strengths are closely related, however, there is no direct proportionality. As the compressive strength of concrete increases, the tensile strength also increases but at a deceasing rate. In general, this ratio ranges from 0.08 to 0.14 and that it exhibit significant scatter (Mindess *et al*. (2003). It has been found out that concrete containing mineral admixtures with adequate curing has a relatively high tensile to compressive strength ratio even at high levels of compressive strength (Shetty, 2006)

The ratio of tensile splitting to compressive strengths, as presented in Table 4, range between 0.078 and 0.123, that is, 7.80% to 12.30%. These values fall within the general range of 0.08 to 0.14 (Mindess et al., 2003) for normal-weight concrete. it is equally noted that within the first 14 days, higher ratio in the range of 0.092 to 0.123 were obtained compared to the ratios at 28 days and 56 days which range between 0.078 to 0.098 and 0.080 to 0.106, respectively. This confirmed the fact that beyond one month, tensile strength increases more slowly than the compressive strength so that the ratio decreases with time (Neville, 2000).

The statistical analysis based on the numerical relationship of tensile strength and compressive strength given by $f_t = K (f_c)^n$ was used in deriving regression equations for the various mixes. The estimated parameters of the model for each of the mix as well as mixes 2 to 6 combined are presented in Table 5, while the regression equations are presented in Table 6.

The results revealed that the values of n for the various mixes are 0.653, 0.707, 0.535, 0.911, 0.596 and 0..295, for mix 1, 2, 3, 4, 5 and 6, respectively; while K values for the same mixes are 0.271, 0.243, 0.383, 0.132, 0.300 and 0.535, respectively. The value for mixes 2-6 combined are 0.873 and 0.141 for n and K, respectively.

The correlation coefficient, R lies between 0.916 and 0.985 indicating a very strong linear relationship between tensile splitting strength and compressive strength of ternary blended cement concrete; meaning that tensile splitting strength can be conveniently estimated from a known value of compressive strength using any of the equations based on the percentage combination of the two cementitious materials in replacing cement in concrete production.

4. Conclusion

From the results of the investigation the following conclusions are drawn:

1. The Periwinkle shell ash has the highest chemical content of CaO while Bamboo leaf ash predominantly content SiO_2 thereby making the two mineral admixtures a complementary cementing materials suitable for ternary blended cement concrete.
2 The slump values lies between 0 and 25mm
3 Concrete with 80%PC-10%PSA-10%BLA content (i.e. mix 2) outperformed that of the reference mix, which is 100%PC only, in both compressive and tensile splitting strengths.
4 The relationship between tensile splitting strength and compressive strength of the combined mixes of ternary blended cement concrete had a higher value, n of 0.873, which is greater than 0.75 for most normal

weight concrete.

5 The correlation coefficient, R lies between 0.916 and 0.985 indicating a very strong linear relationship between tensile splitting strength and compressive strength of ternary blended cement concrete.

6 A blended mix combination of 75%PC-15%PSA-10%BLA (i.e. mix 3) could be used for mass concrete production where early strength requirement is not paramount.

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Table 1: composition of cementitious materials in Ternary blended cement concrete

Designation	Percentage Composition (by mass)		
	PC	PSA	BLA
Mix 1	100	0	0
Mix 2	80	10	10
Mix 3	75	15	10
Mix 4	70	20	10
Mix 5	65	25	10
Mix 6	60	30	10

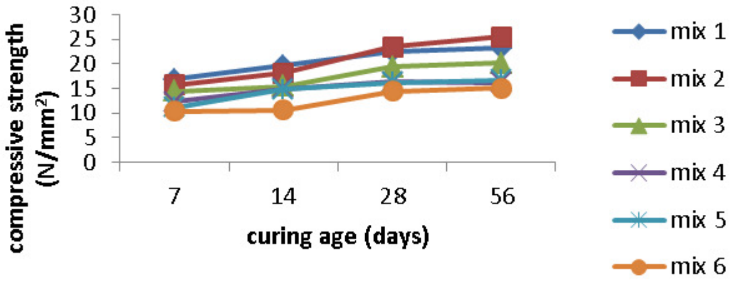

Fig. 1: Variation of compressive strength with curing age for various mixes

Table 2: Compressive strength of Ternary blended cement concrete for various curing ages

Curing age (days)	% Composition (by mass)			Compressive strength (N/mm^2)				Reference strength ((%)
	PC	PSA	BLA	1	2	3	Mean	
7	100	0	0	17.5	16.00	17.00	16.83	100.00
	80	10	10	15.83	15.40	15.90	15.71	93.35
	75	15	10	14.00	14.75	14.60	14.45	85.86
	70	20	10	12.25	12.17	12.60	12.34	73.32
	65	25	10	11.17	11.10	11.25	11.17	66.39
	60	30	10	10.50	9.95	10.70	10.38	61.70
14	100	0	0	19.50	20.00	19.60	19.70	100.00
	80	10	10	18.00	18.40	17.80	18.07	91.71
	75	15	10	15.80	15.50	15.10	15.47	78.51
	70	20	10	14.80	15.00	15.20	15.00	76.14
	65	25	10	14.70	14.80	14.95	14.82	75.21
	60	30	10	10.70	11.00	10.10	10.60	53.81
28	100	0	0	22.70	22.10	22.40	22.40	100.00
	80	10	10	23.45	23.15	23.70	23.43	104.61
	75	15	10	19.50	19.75	19.00	19.42	86.68
	70	20	10	16.30	16.65	16.10	16.35	72.99
	65	25	10	16.10	16.50	16.00	16.20	72.32
	60	30	10	14.75	14.10	14.60	14.48	64.66
56	100	0	0	23.20	23.10	23.50	23.27	100.00
	80	10	10	25.80	25.60	25.10	25.50	109.58
	75	15	10	20.75	20.10	20.80	20.22	86.89
	70	20	10	16.25	16.00	16.50	16.25	69.83
	65	25	10	16.50	16.00	16.00	16.17	69.47
	60	30	10	14.80	15.20	15.30	15.10	64.89

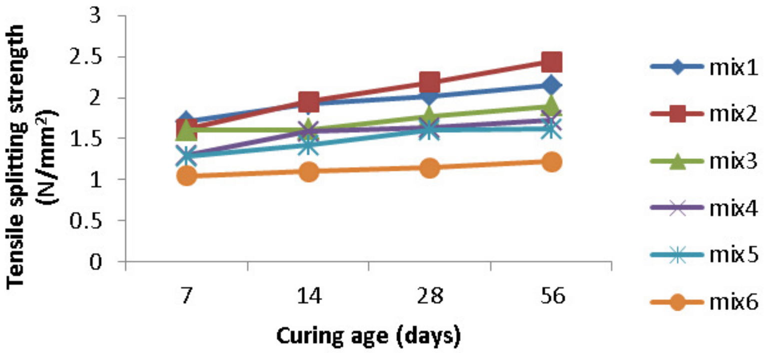

Fig. 2: Variation of tensile splitting strength with curing age for various mixes

Table 3: Tensile splitting strength of Ternary blended cement concrete for various curing ages

Curing age (days)	% Composition (by mass)			Tensile splitting strength (N/mm^2)				Equivalent of reference (%)
	PC	PSA	BLA	1	2	3	Mean	
7	100	0	0	1.68	1.72	1.74	1.71	100.00
	80	10	10	1.70	1.64	1.66	1.67	97.66
	75	15	10	1.60	1.59	1.62	1.60	93.57
	70	20	10	1.32	1.30	1.28	1.30	76.02
	65	25	10	1.28	1.27	1.30	1.28	74.85
	60	30	10	0.95	1.10	1.10	1.05	61.40
14	100	0	0	1.92	1.94	1.90	1.92	100.00
	80	10	10	1.96	1.98	1.92	1.95	101.74
	75	15	10	1.59	1.62	1.63	1.61	84.03
	70	20	10	1.59	1.59	1.60	1.59	82.99
	65	25	10	1.40	1.40	1.46	1.42	73.95
	60	30	10	1.08	1.14	1.08	1.10	57.29
28	100	0	0	2.04	2.00	2.02	2.02	100.00
	80	10	10	2.16	2.20	2.20	2.19	108.42
	75	15	10	1.78	1.74	1.78	1.77	87.62
	70	20	10	1.61	1.63	1.65	1.63	80.69
	65	25	10	1.60	1.61	1.59	1.60	79.21
	60	30	10	1.14	1.16	1.15	1.15	59.93
56	100	0	0	2.16	2.08	2.20	2.15	100.00
	80	10	10	2.42	2.44	2.46	2.44	113.49
	75	15	10	1.89	1.91	1.90	1.90	88.37
	70	20	10	1.72	1.73	1.73	1.72	80.00
	65	25	10	1.60	1.64	1.62	1.62	75.35
	60	30	10	1.22	1.20	1.24	1.22	56.74

Table 4: The ratio of tensile splitting and Compressive strength of ternary blended cement concrete

Curing age (days)	% Composition (by mass)			Compressive strength (N/mm^2)	Tensile splitting strength (N/mm^2)	Tensile/Compressive strength	
	PC	PSA	BLA			Ratio	Percentage
7	100	0	0	16.83	1.71	0.101	10.16
	80	10	10	15.71	1.67	0.106	10.63
	75	15	10	14.45	1.6	0.110	11.07
	70	20	10	12.34	1.3	0.105	10.53
	65	25	10	11.17	1.28	0.114	11.46
	60	30	10	10.38	1.05	0.101	10.11
14	100	0	0	19.7	1.92	0.097	9.75
	80	10	10	18.07	1.95	0.107	10.79
	75	15	10	15.47	1.61	0.104	10.41
	70	20	10	15	1.59	0.106	10.60
	65	25	10	14.82	1.42	0.095	9.58
	60	30	10	10.6	1.10	0.104	10.38
28	100	0	0	22.4	2.02	0.090	9.02
	80	10	10	23.43	2.19	0.093	9.35
	75	15	10	19.42	1.77	0.091	9.11
	70	20	10	16.35	1.63	0.099	9.97
	65	25	10	16.2	1.6	0.098	9.88
	60	30	10	14.48	1.15	0.079	7.94
56	100	0	0	23.27	2.15	0.092	9.24
	80	10	10	25.5	2.44	0.095	9.57
	75	15	10	20.22	1.9	0.093	9.40
	70	20	10	16.25	1.72	0.105	10.58
	65	25	10	16.17	1.62	0.100	10.00
	60	30	10	15.1	1.22	0.081	8.08

Table 5: parameters estimate for tensile splitting and compressive strength relationship of Ternary blended cement concrete.

% Composition (by mass)			Model parameters		R^2	R
PC	PSA	BLA	n	K		
100	0	0	0.653	0.271	0.970	0.985
80	10	10	0.707	0.243	0.962	0.981
75	15	10	0.535	0.383	0.891	0.944
70	20	10	0.911	0.132	0.952	0.976
65	25	10	0.596	0.300	0.896	0.947
60	30	10	0.295	0.535	0.846	0.920
Combined mixes 2-6			0.873	0.141	0.839	0.916

Table 6: Regression equations for ternary blended cement concrete

Designation	% Composition (by mass)			Derived regression equations
	PC	PSA	BLA	
Mix 1	100	0	0	$F_t = 0.271(f_c)^{0.653}$
Mix 2	80	10	10	$F_t = 0.243(f_c)^{0.707}$
Mix 3	75	15	10	$F_t = 0.383(f_c)^{0.535}$
Mix 4	70	20	10	$F_t = 0.132(f_c)^{0.911}$
Mix 5	65	25	10	$F_t = 0.300(f_c)^{0.596}$
Mix 6	60	30	10	$F_t = 0.535(f_c)^{0.295}$
Combined mixes 2-6				$F_t = 0.141(f_c)^{0.873}$

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