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Exploring the Effects of Pozzolans on Different types of Portland Cements in Sustainable Cement-Based Applications

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Abstract: The sources of pozzolans could be natural, industrial and agricultural wastes that are recycled into concrete and mortar applications. There have also been many studies and recommendations guiding the use of blending these pozzolans from multiple sources with cement with the aim of producing more durable, greener and sustainable mortar/concrete. These investigations are mostly based on testing these pozzolans with a certain type of cement and making recommendations on the optimum percentage replacements. This type of study underscores that a pozzolan can behave differently with other types of Portland cements with varying distinct chemical compositions that associate the cement with its type. This could result to a particular pozzolan having different optimum percentage cement replacements with different types of cement and hence results in less durable concrete of which this study intends to address. The pozzolan used in this study is Pulverized Calcined Clay (PCC) and the types of cement is based on the British and American standards classification. The cement variants used in this study is broadly rapid hardening and low heat cement form the two (2) major cement brands in Nigeria. The X-Ray Fluorescence (XRF) analysis was performed on the cements and the PCC to determine their oxide compositions and classify the pozzolan, the Strength activity index (SAI) of the pozzolan was also determined. The optimum percentage replacements (replacement level with maximum strength) of the cements with the pozzolan was also determined. The results indicate that the optimum replacements for the low-heat cement was at 20% replacement with PCC and substantially higher for the rapid-hardening cement. This could be adduced to the difference in the chemical compositions as shown in the XRF analysis. It was concluded that the optimum replacement of different cement types with a pozzolan could vary, resulting to less durable concrete when a single optimum replacement is recommended across all cement types. It is therefore recommended that the optimum replacements of cements with pozzolans should be specific to a cement type and recommended that optimum replacement for other cement types with same pozzolan be determined and not generalized across all cements.

1.   Introduction

Portland Cement (PC) is undoubtedly the most used binder globally in concrete and construction applications. And PC is the major constituent in concrete, which is adjudged as the most consumed man-made material with the highest carbon dioxide (CO_2) foot-print globally [1]. A study by [2] reveals that PC concrete production contributes to over seven percent (7%) of the global greenhouse gas (GHG) emission and bulk of this emission is associated with the CO_2 generated during the production of the cement used in the concrete. From the aforementioned, PC is significantly a non-sustainable material. Researchers are now focusing their research on diminishing the use of PC in concrete applications with a view to eliminating the carbon footprint associated with concrete, thus necessitating a global shift from the use of cement as a binder to other materials that is more

sustainable and environmentally friendly. There are current researches on the use of geopolymer and pozzolan as binders in concrete applications and has been proven to possess the potential to partially or fully replace cement in concrete [2,3,4].

Pozzolans, which is the focus of this study and derived from different sources, have been widely studied and were proven to possess the capacity to replace PC at various degrees in concrete works. The subject of these researches is mostly to ascertain pozzolanic activities and at what degree they could replace PC, but the degree of replacement with different types of PC is scarcely studied.

This study is to compare the pozzolanic activity of pozzolans with different types of PC's with a view to verify for possible differing behavior of these PC types with pozzolans. The PC types will be based on British classification [5] and the American classification [6].

2. Materials and Methods

2.1 Materials

The pozzolan used in this study is Pulverized Calcined Clay (PCC) produced by the Nigeria Building and Road Research Institute (NBRRI). The cements used are brand Dangote CEM II 42.5N, Lafarge CEM II 42.5N, Dangote CEM II 42.5R and Lafarge CEM II 32.5N. These cements were sourced from the local market within the study area. The fine aggregate used in this study is the special sand specified in [7] for the determination of the strength of cement. The sand is a river dredged sharp sand that was thoroughly washed, oven-dried and sieved to simulate the special sand. While the water is a borehole water sourced with the Covenant University premises.

2.2 Methods

The data in this study were obtained by experimental procedures. The various cement types and brands was replaced with the pozzolan, PCC, by 15% to 30% in steps of 5% and the binder strength determined in accordance to BS EN 196-1:2005. The X-Ray Fluorescence (XRF) analysis was performed on the cements and the PCC to determine their oxide compositions and classify the pozzolan, the Strength activity index (SAI) of the pozzolan was also determined for all the cement types. The optimum percentage replacements (replacement level with maximum strength) of the cements with the pozzolan was also determined. The optimum strengths were now analyzed to conclude if there were strength variations and draw out possible reasons for the variations from all tests carried out.

3. Results and Discussions

From the methods and laboratory procedures described, the following results was obtained and discussed.

3.1 Oxide Composition and Chemical Analysis of the PCC and Cements

Table 1: XRF Analysis of the Cements and PCC

Cement Types		D42.5N	L42.5N	D42.5R	L32.5N	PCC (NBRRI, 2016)
Percentage oxide compositions	SiO_2	17.95	21.79	21.48	19.01	66
	Al_2O_3	4.85	5.2	4.06	4.97	18.56
	Fe_2O_3	2.89	1.2	5.46	2.92	6.68
	CaO	61.52	64	62.18	64.37	0.7
	MgO	3.45	2.9	0.81	1.74	0.56
	Na_2O	0.10	0.6	0.13	0.47	0.05
	K_2O	0.32	0.0	0.64	0.27	0.24
	SO_3	1.64	4.5	2.56	2.45	0.03
LOI		7.93	0.0	12.28	5.16	4.9
$Fe_2O_3 + SiO_2 + Al_2O_3$						91.42
Percentage cement	C_3S	72.62	45.28	47.39	72.96	-
	C_2S	-3.31	28.32	25.85	-0.51	-

composition	C_3A	7.95	11.65	1.52	8.23	-
	C_4AF	8.80	3.35	16.61	8.89	-

According to [8], the NBRRI's PCC is a class N pozzolan since the sum of the percentage compositions of Fe_2O_3, SiO_2 and Al_2O_3 is more than 70%. Loss On Ignition (LOI) is less than ten (10%), SO_3 is less than 4% and its natural source justifies this classification. This class of pozzolan is expected to possess higher activity than other classes. The PCC was sieved with a 75-micron sieve size.

3.2   Grading of the fine aggregate (special sand)

The result of the sieve analysis is shown in Figure 1

From the particle size distribution of the sand in Figure 1, the sand is classified as a poorly graded sand (SP) using the USCS since the Coefficient of Uniformity (Cu) is 6 and the Coefficient of Curvature (Cc) is 0.53 as derived from Figure 1. Poorly graded as classed in this case does not connote its bad but that it is close to being a uniformly graded sand. This sand satisfies the requirements stipulated in [5] for the determination of binder strength.
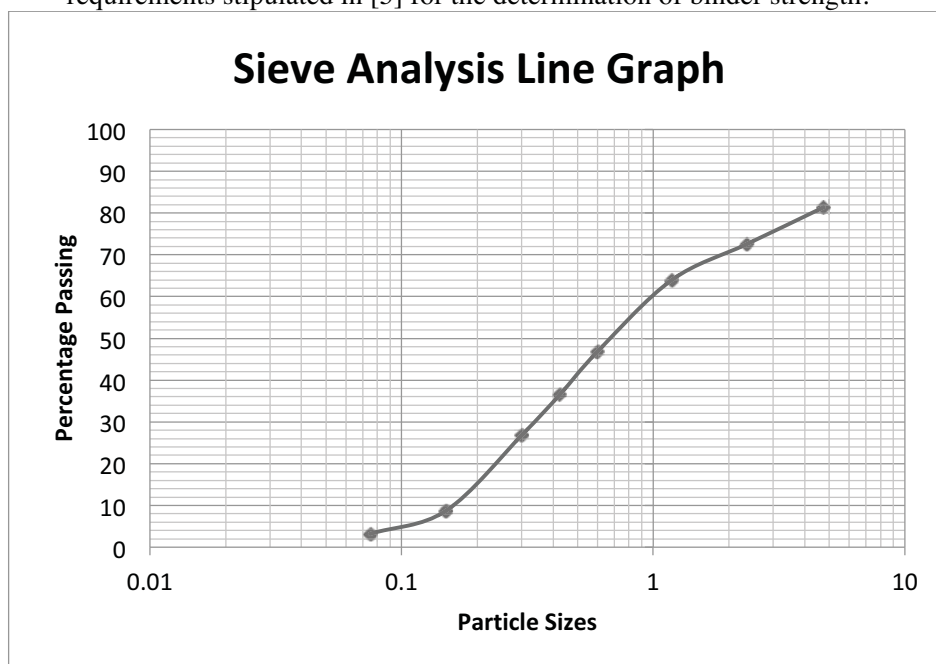

Figure 1: Particle Size Distribution of the Fine Aggregate for All Mortar Strengths

3.3   Mortar Strength Results of the Various Cement Brands with the Pozzolan

The individual graphs show the relation between the pozzolan and different types of cement and the pozzolanic activity on each type, on Figures (2 - 5). Note that all compressive strength values are in mega pascal (N/mm²)

It was observed that all replacements where greater than the control (0% replacement with PCC) which indicates a pozzolanic activity and the optimum strength at 28-day (13.45 MPa and 13.2MPa) was obtained at 25% replacements as observed in Figure 2A. The percentage strength at 20% replacement at 28-day is 106.78% of the control. Therefore, the strength activity index of PCC on Dangote 42.5N class is 106.78% as shown in Figure 2C. The optimum strength was attained at 25% replacement. Figure 2B. shows that the strength increases with age.
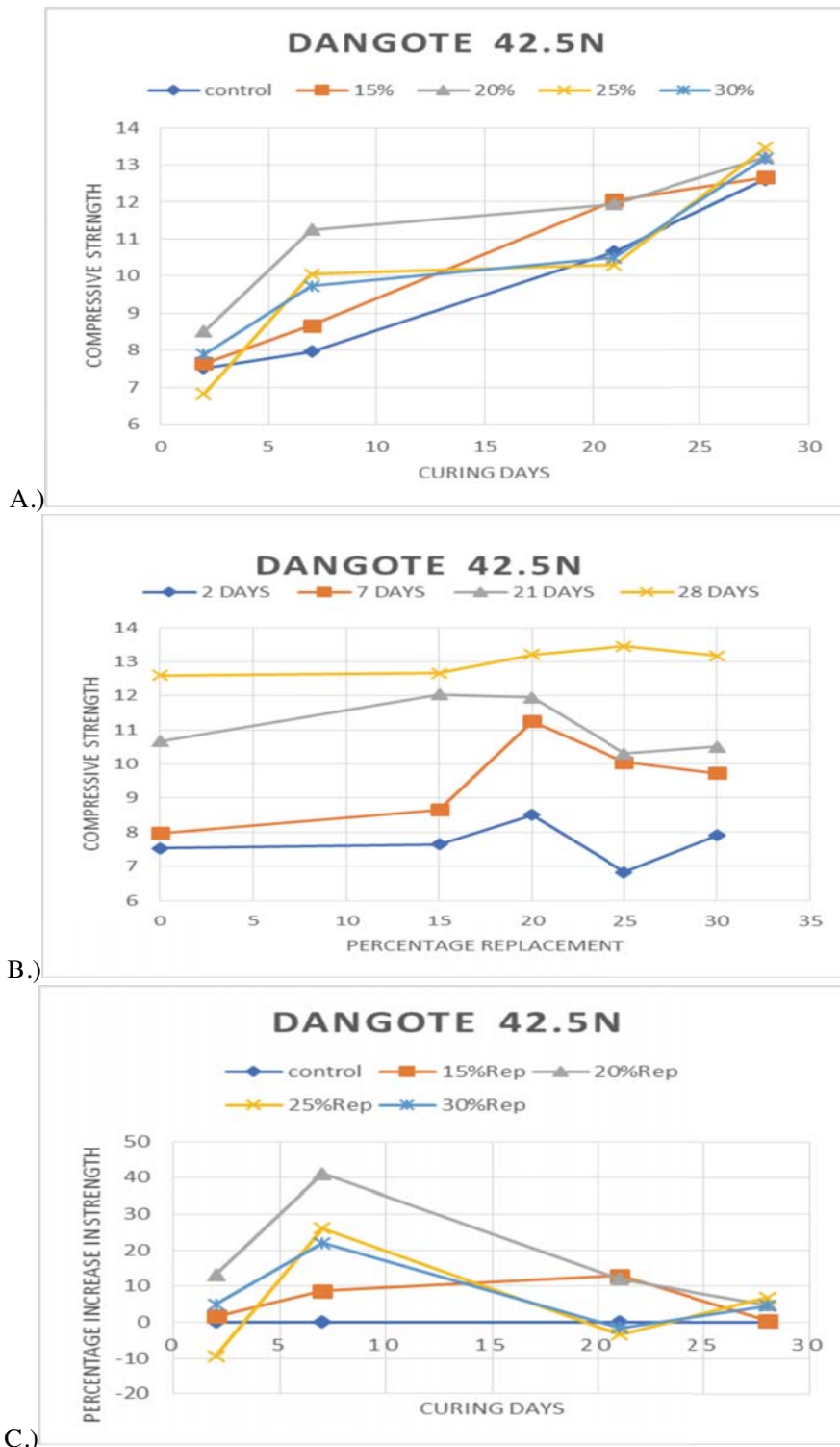
Figure 2: Mortar Strength of and Percentage Increase of Dangote 42.5N cement/pozzolan at Different Curing Days
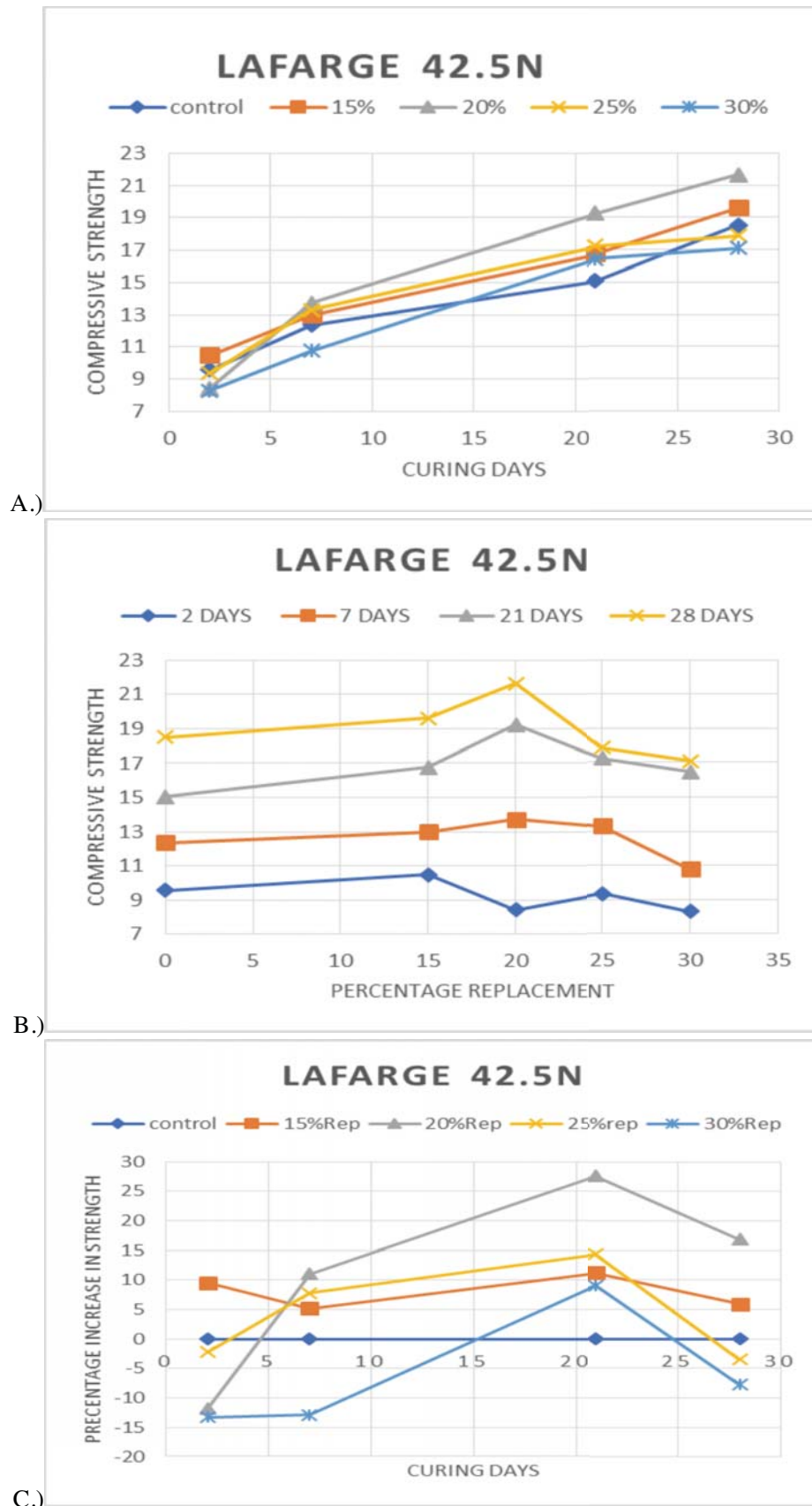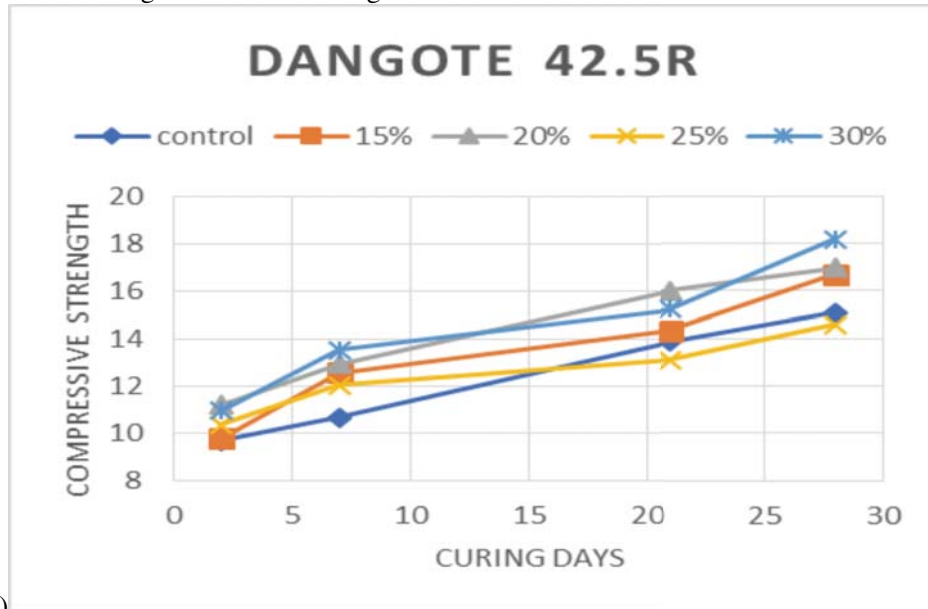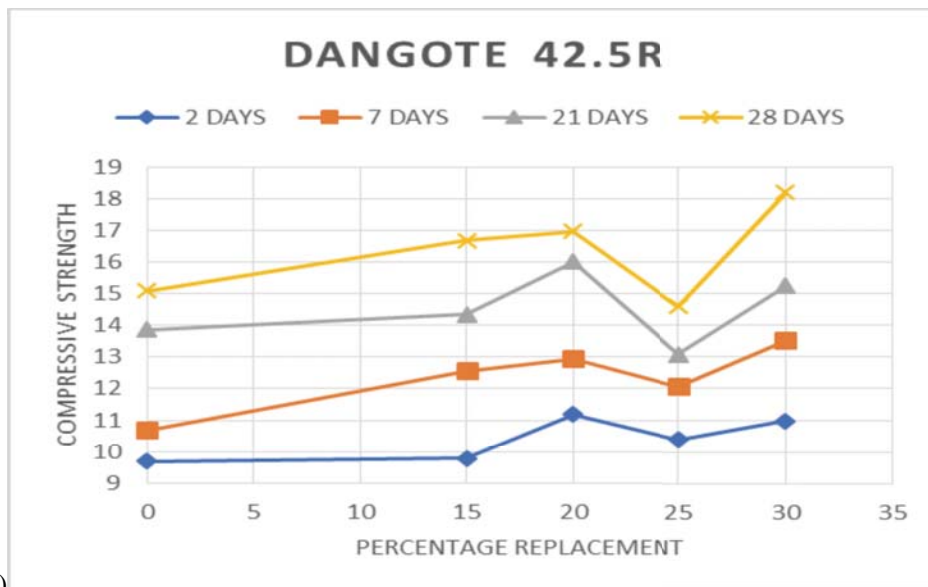
A.)

B.)

C.)

Figure 3: Mortar Strength and percentage increase of Lafarge 42.5N Cement/Pozzolan at Different Curing Days
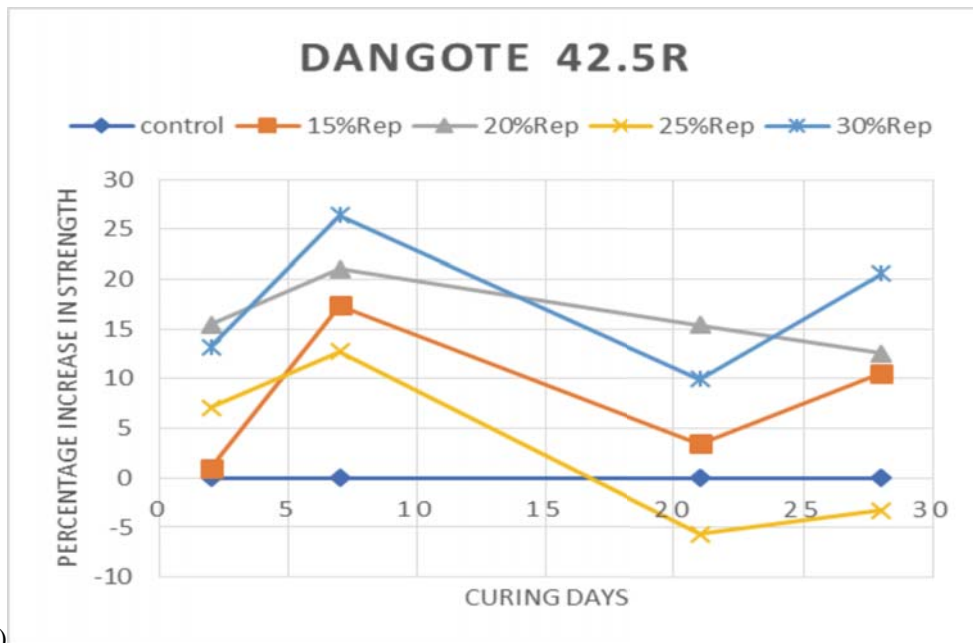
It was observed that some replacements where greater that the control (0% replacement with PCC) which also indicates a pozzolanic activity and the optimum strength at 28-day (21.64MPa) was obtained at 20% replacement as observed in Figure 3A. The percentage strength at 20% replacement at 28-day is 109% of the control. Therefore, the strength activity index of PCC on Lafarge 42.4N class is 109% as seen in Figure 3C. The optimum strength was attained at 20% replacement. Figure 3B. show that the strength increases with age.
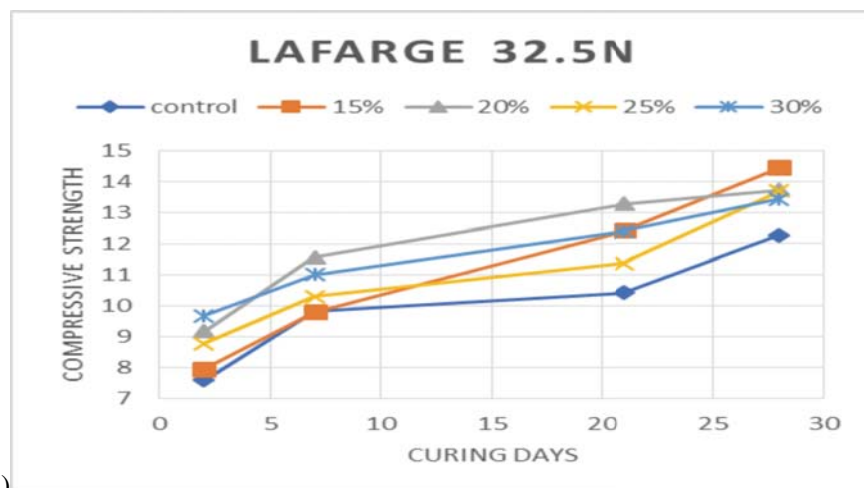

A.)

B.)

C.)

Figure 4: Mortar Strength and Percentage Increase of Dangote 42.5R Cement/Pozzolan at Different Curing Days

It was observed that all replacement except for the 25% replacement where greater than the control (0% replacement with PCC) which indicates a pozzolanic activity and the optimum strength at 28-day (28.28MPa) was obtained at 30% replacement as observed in Figure 4A. The percentage strength at 20% replacement at 28-day is 112.5% of the control. Therefore, the strength activity index of PCC on Dangote 42.5N class is 112.5% as shown in Figure 4C. The optimum strength was attained at 30% replacement. It also follows the sequence that the strength increases at the increasing curing days as shown in Figure 4B.
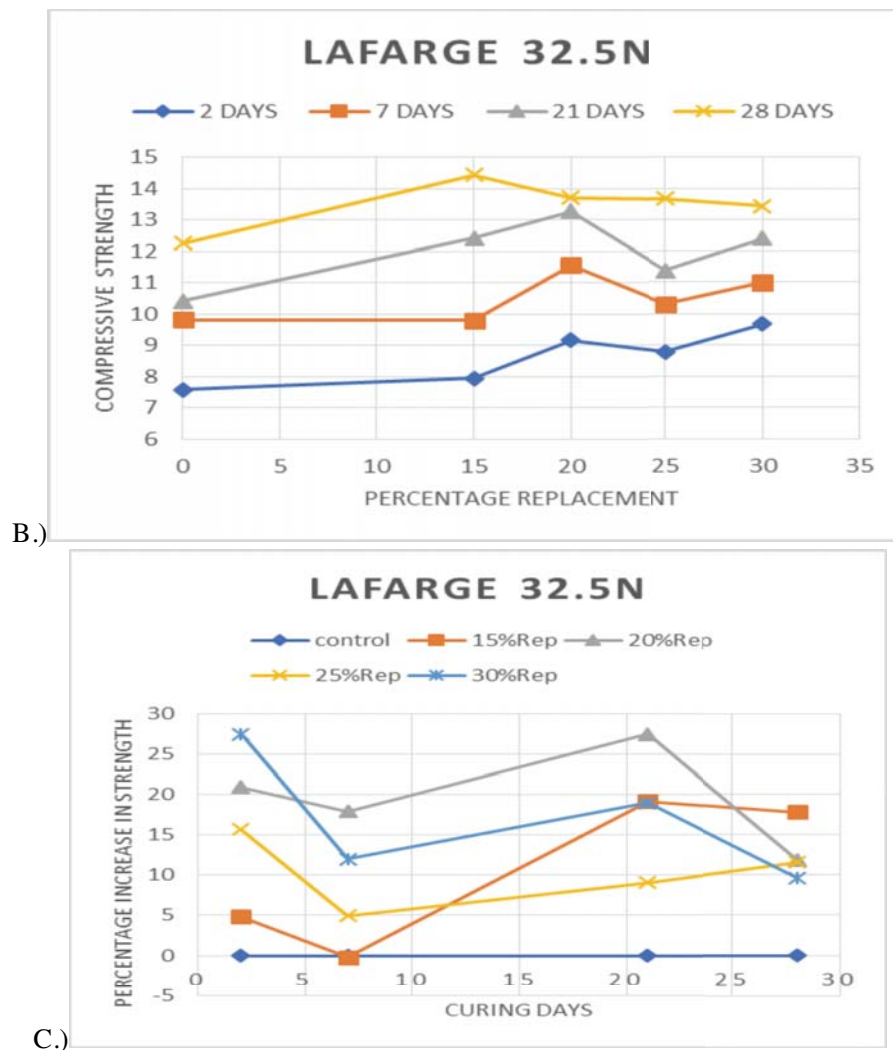

A.)

B.)

C.)

Figure 5: Mortar Strength and Percentage Increase of Lafarge 32.5R Cement/Pozzolan at Different Curing Days

It was observed that all replacement where greater than the control (0% replacement with PCC) which indicates a pozzolanic activity and the optimum strength at 28-day (14.44MPa) was obtained at 15% replacement as observed in Figure 5A. The percentage strength at 20% replacement at 28-day is 111.9% of the control. Therefore, the strength activity index of PCC on Lafarge 32.5N is 111.9% as seen in Figure 5C. The optimum strength was attained at 15% replacement. It also follows the sequence that the strength increases at the increasing curing days as shown in Figure 5B. The total overview and observation of the work is that the optimum strength for Dangote 42.5N is at 25% replacement, for Lafarge 42.5N is at 20% replacement, for Dangote 42.5R is at 30% replacement and for Lafarge 32.5N is at 15% replacement. They all have their strength increased as the curing days increases.

4 CONCLUSION AND RECOMMENDATION

4.1 Conclusions

The pozzolan used was Pulverised Calcined Clay and from the result in Figure 2 to Figure 5, the following conclusions were made:

- From the XRF analysis, since the sum of the oxide composition of Fe_2O_3, SiO_2 and Al_2O_3 are more than 70%, it is classified as a class N pozzolan [8], by implication it's expected to be from a natural source. The pozzolan is from a natural clay deposit and has higher pozzolanic activity index property.

- The PCC demonstrates a high strength of pozzolanic activity for all the different types of cement.
- The Dangote 42.5N has the highest strength at 25% replacement in 28-days and a strength activity index at 28-day is 104.8% of the control.
- The Lafarge 42.5N has the highest strength at 20% replacement in 28-days and a strength activity index at 28-days is 109% of the control.
- The Dangote 42.5R has the highest strength at 30% replacement in 28-days and a strength activity index at 28-days is 112.5% of the control.
- The Lafarge 32.5N has the highest strength at 15% replacement in 28-days and a strength activity index at 28-days is 111.9% of the control.
- The cements with normal hardening (abbreviated 'N') rate was optimised with the PCC at lower replacements than the rapid hardening (abbreviated 'R'). The low heat cements (CEM II 32.5N) was optimised with PCC at even lower replacements than the normal hardening cements.
- A particular pozzolan could have varying pozzolanic indices when blended with different types of cements.
- It was observed that they all have their strength increased as the curing days increases.

4.2 Recommendation

Due to the above conclusion, it is recommended that:

- The PCC used in this study is a good pozzolan with high pozzolanic activity index in strength and composition.
- It was discovered that fine dredged sand that has been sieved to achieve a finer aggregate would be preferable for a mortar mix.
- It could be suitable to use the Dangote 42.5N cement at 25% replacement with PCC, Lafarge 42.5N cement at 20% replacement with PCC, Dangote 42.5R cement at 30% replacement with PCC and Lafarge 32.5N cement at 15% replacement of PCC. But should always be confirmed with a trial mix in all cases.
- A particular pozzolan could have varying pozzolanic indices when blended with different types of cements, hence, pozzolanic indices should be related to only a particular type of cement and not generalised across all cement types.

References

[1] Naik, T.R. (2008). Sustainability of Concrete Construction. *Practice Periodical on Structural Design and Construction, American Society of Civil Engineers (ASCE). 13(2), 98-103.*

[2] Al Muhit B. A., Foong, K. Y., Alengaram U. J. and Jumaat, M. Z. (2013). Geopolymer Concrete: A Building Material for the Future. *Electronic Journal of Structural Engineering 13(1) 11-15*

[3] Joshua, O., Fagbenle, O. I, Olusola, K. O., Shamaki, S. J., Abuka-Joshua, J., Ogunde, A. O., Amusan, L. M., and Omuh, I. O. (2018). Pulverized Calcined Clay and Carbide Waste as Alternative Binder in Concrete and Mortar Applications for Sustainable Construction. In Chao Wang, Christofer Harper, Yongcheol Lee, Rebecca Harris and Charles Berryman (Eds), *Infrastructure and Facility Management,* Construction Research Congress (CRC) of the American Society of Civil Engineers (ASCE). New Orleans, Louisiana. USA. *675-684.* ISBN 978-0-7844-8126-4.

[4] Joshua, O., Matawal, D. S., Akinwumi, T. D., Olusola, K. O., Ogunro, A. S. and Lawal, R. B. (2018). Development of A FullyPozzolanic Binder for Sustainable Construction: Whole Cement Replacement in Concrete Applications*. International Journal of Civil Engineering and Technology. 9(2), 1–12.*

[5] BS EN 197-1 (2011). Cement Part 1: Composition, Specifications and Conformity Criteria for Common Cements. British Standard Institute. London.

[6] ASTM C150 / C150M-(2018) Standard Specification for Portland Cement, ASTM International, West Conshohocken, PA, 2018, www.astm.org

[7] BS EN 196-1 (2005). Methods of Testing cement. Determination of Strength. British Standard Institute. London

[8] ASTM C 618-(2015), Standard specification for Coal, Fly Ash and Raw Calcined Natural for use in concrete, ASTM International, West Conshohocken, PA, 2015,   www.astm.org