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MODELLING REVIEWED HYDRAULIC INDICES OF PERIWINKLE SHELL ASH OCCASIONED BY VARIATIONS IN CALCINATION TEMPERATURE

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ABSTRACT: *Periwinkle shellfish can be found in abundance in the Niger Delta's wetlands. Periwinkle shells are frequently piled in open fields and landfills, resulting in pollution and the development of disease-carrying organisms. Attempts have been made to employ periwinkle shell ash (PSA) as recycled materials in cement-based products in order to manage periwinkle shell by-products, preserve natural resources, and minimize building expenses. A better understanding of results obtained can be established using statistical tools in the analysis and modelling of the trends established with respect to reviewed papers on the PSA production parameters as well as the cement replacement level on the mechanical indices of concrete. This paper, therefore, uses statistical templates to develop analyzed models for a more enhanced understanding of trends and patterns associated with PSA processing variables and cement replacement levels on the compressive strength of concrete.*

KEYWORDS: Hydraulicity indices, Cementation indices, Pozzolanicity, Calcination, Compressive strength.

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INTRODUCTION

Periwinkle is a mollusc shellfish whose shell is the by-product of removing the edible component of the periwinkle shellfish. Fishing and fishery are the means to raising shellfish. Winkles, abalones, and conchs account for about 2.8 percent of the 16 million tonnes of mollusk shellfish produced by aquaculture each year worldwide (FAO, 2014 quoted in Yang et al., 2016; FAO, 2016). The shell, which is a challenge for shellfish growers, merchants, and consumers, is a concern in shellfish food production (Morris et al., 2018).

Periwinkle shell remnants are commonly piled in open fields and landfills, resulting in a foul odour, ugly appearance, and the development of disease-carrying organisms. Periwinkle shell dumps can be found in various Niger Delta towns and cities, including Port Harcourt, Uyo, Calabar, Yenagoa, Warri, and Oron (Ohimain et al., 2009). Various approaches have been tried to address the waste management issues related with periwinkle shell (Table 1). Some of the periwinkle shell's potential applications necessitates additional processing steps such as crushing and calcination (Eziefula et al., 2020). Periwinkle shells could be used in concrete and other cement-based products like sandcrete and mortar as recycled resources.

The large volume of cement produced and consumed is due to the rapid development of the construction industry. The most common type of cement available is Portland cement. Cement is so important to humans that it is commercially manufactured in over 150 countries and produced in excess of 3.5 billion metric tonnes per year (McLeod, 2005; UNEP Global Environmental Alert Service, 2014).

Carbonate oxidation in the cement clinker manufacturing process accounted for about 5% to 8% of total global carbon dioxide (CO2) emissions (Olivier et al., 2016). CO2 and other greenhouse gases released into the atmosphere are the primary cause of climate change, which is today a critical global environmental issue. Partially replacing cement with supplementary cementitious materials (SCMs) is one way to reduce CO2 emissions from the current cement manufacturing process. These SCMs are by-products that are used in cement-based materials as fillers or pozzolans. In the hardened condition, one of the most essential features of concrete is its compressive strength. The resistance to compressive loads is the primary consideration in the construction of concrete structures. Compressive strength is the quality criterion in structural design (Umoh & Olusola, 2013; Neville, 2010).

Cementation and hydraulic indexes are parameters mainly dependent on the oxide compositions of silicon, aluminum, iron, magnesium and calcium. Figueiredo et al. (2016) noted that silicon and aluminum oxides are the primary oxides responsible for the hydraulic behavior of a material. In the discussion of their findings, they asserted that at higher calcination temperatures, greater amounts of Alite (C3S) are produced.

Findings of Herbert et al. (2019) showed that Hydraulicity Index (HI) is directly proportional to Cementation Index (CI) as well as compressive strength, on the condition that all samples are prepared to have an approximate uniform fineness. This could explain the variation observed in the findings of Figueiredo et al. (2016) in which NHL2-B had a better cementation and Hydraulic Indexes when compared to NHL2-A, but was found to be lower in compressive strength as the fineness of both samples was not defined.

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Table 1: Some applications of periwinkle shells in environmental management, construction industry and economic advancement (Eziefula et al., 2020).

S/N	Application	Reference
1	Substitute coarse aggregate in concrete construction	Agbede and Manasseh (2009), Ohimain et al. (2009), Ekop et al. (2013), Ettu et al. (2013[b]), Osarenmwinda and Awaro. (2009)
2	Supplementary cementitious material in cement-based construction materials	Etuk et al. (2012), Olusola and Umoh (2012), Umoh and Olusola (2012, 2013) and Etim et al. (2017)
3	Lime substitute in glass manufacturing	Malu and Bassey (2003)
4	Formulation of fish feed; livestock food (calcium) supplement	Oribhabor and Ansa (2006)
5	Liming agent in soil stabilization	Otoko and Cynthia (2014), Otoko and Welcome (2014) and Nnochiri (2017)
6	Biofilter medium; treatment of wastewater contaminated with heavy metals; pH buffering medium in aquaculture	Badmus et al. (2007), Badmus and Audu (2009), Awokoya et al. (2016), Davies and Ogidiaka (2017) and Ugwuoha et al. (2017)
7	Particle board production	Abdullahi and Sara (2015)
8	Automotive brake pad	Yawas et al. (2016) and Dan-asabe and Stephen (2018)
9	Pharmaceutical excipient	Ugoeze and Chukwu (2015) and Ugoeze and Udeala (2015)
10	Filling material for potholes in pavements	Ohimain et al. (2009)
11	Cleaning/cleansing agent	Bob-Manuel (2012) and Ademolu et al. (2015)
12	Aesthetic and decorative purposes; ornamentals; bead making	Bob-Manuel (2012) and Soneye et al. (2016)

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Table 2: Relating hydraulicity index to the compressive strength of pozzolana concrete (Herbert et al., 2019)

Pozzolan ID Based on 28day curing age @30 Cem. replacement level		Calcination Temperature						
		500°C	600°C		700°C	750°C	800°C	Ref OPC
Ar - A	Comp. Strength (Mpa)	41.1	45.7		45.7	47.4	47.8	58.4
	Hydraulic Index	-4.22	23.49		23.49	33.73	36.14	
Ar - B	Comp. Strength (Mpa)	42.0	43.1		49.8	48.1	48.2	58.4
	Hydraulic Index	1.45	8.01		48.19	37.83	38.25	
		600°C	700°C	750°C	800°C	850°C	900°C	Ref OPC
Ar - C	Comp. Strength (Mpa)	40.07	41.0	43.6	43.9	41.3	43.0	59.9
	Hydraulic Index	-6.08	-4.42	9.94	11.82	-2.87	6.57	
Ar - C	Comp. Strength (Mpa)	40.3	41.4	46.5	56.8	48.8	43.3	59.9
	Hydraulic Index	-8.29	-2.21	25.97	82.87	38.67	8.29	

Table 3: Oxide composition. Cementation and hydraulicity index (Figueiredo et. al., 2016)

Oxide	NHL – 2A	NHL – 2B	NHL – 2C
CaO	66.38	66.03	66.41
SiO_2	7.80	9.35	4.85
Al_2O_3	1.63	0.38	0.12
MgO	2.37	0.44	1.19
Fe_2O_3	2.10	0.38	0.5
SO_3	0.37	0.46	1.19
K_2O	0.89	0.33	0.46
Na_2O	0.31	0.49	0.49
TiO_2	0.16	0.09	0.09
MnO	0.05	0.01	0.01
LOI	17.95	22.03	24.64
CI	0.36	0.40	0.21
HI	0.14	0.15	0.07

Table 2 illustrates the peculiar effect of calcination on the hydraulicity of pozzolans which invariably affects compressive strength contribution of the pozzolan in concrete when used as a supplementary cementitious material. Table 3 contributes by showing as a way of example the correlation between the oxide composition of cementitious materials and their hydraulicity/cementitious indices.

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MATERIALS AND METHODS

The investigation primarily intends to fill the gap of the ideal temperature for optimum hydraulicity of periwinkle shell ash as a partial cementitious material in concrete. Using oxide composition findings from Etim et al. (2017), Etuk et al. (2012), Job et al. (2017), Nnochiri (2017), Offiong and Akpan (2017), Umoh and Olusola (2012), and the equations for hydraulicity as well as cementitious indices, resulting data were used as inputs in a surface response methodological design from Design Expert analytical tool, to analyze and develop a model for monitoring the hydraulic potentials of PSA in PSA cement blended concrete.

$$Cl = \frac{2.8SiO_2 + 1.1Al_2O_3 + 0.7Fe_2O_3}{CaO + 1.4MgO} \qquad 1.0$$

$$Hl = \frac{SiO_2 + Al_2O_{33}}{CaO} \qquad 2.0$$

RESULTS AND DISCUSSION

Table 4: Hydraulic and cementation indices of PSA effected by variations in calcination temperature

Reference	Temp	Weight of elemental oxide (%)								
	(ºC)	CaO	SiO2	Al2O3	Fe2O3	MgO	Na2O	K2O	CI	HI
Etim et al. (2017)	1000	42.32	29.54	11.6	5.13	0.42	0.43	0.11	2.31	0.97
Nnochiri (2017)	1000	41.35	35.37	9.6	4.84	0.5	0.21	0.2	2.69	1.09
Offiong and Akpan (2017)	1000	46.39	30.8	10.84	5.58	0.73	0.27	0.27	2.15	0.90
Average	**1000.00**	**43.35**	**31.90**	**10.68**	**5.18**	**0.55**	**0.30**	**0.19**	2.38	0.99
Etuk et al. (2012)	800	55.53	26.26	8.79	4.82	0.4	0.25	0.2	1.54	0.63
Job et al. (2017)	800	37.54	34.74	15.57	0.12	0	0	0.03	3.05	1.34
Offiong and Akpan (2017)	800	40.63	33.85	10.24	6.25	0.83	0.15	0.26	2.64	1.09
Umoh and Olusola (2012)	800	40.84	33.84	10.2	6.02	0.48	0.24	0.14	2.65	1.08
Average	**800**	**43.64**	**32.17**	**11.20**	**4.30**	**0.43**	**0.16**	**0.16**	2.47	1.03
Offiong and Akpan (2017)	600	38.62	23.32	9.62	5.01	0.36	0.24	0.13	2.03	0.85

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From the figure (Figure 1), it can be said that a quadratic trend exists between calcination temperature and the hydraulicity of periwinkle shell ash as a cementing material. Whilst 800oC appears to be optimal for hydraulicity index, 900oC appears to be more suitable for cementation index. It can be observed, however, that no significant difference in hydraulicity index is observed between 600°C and 1000°c

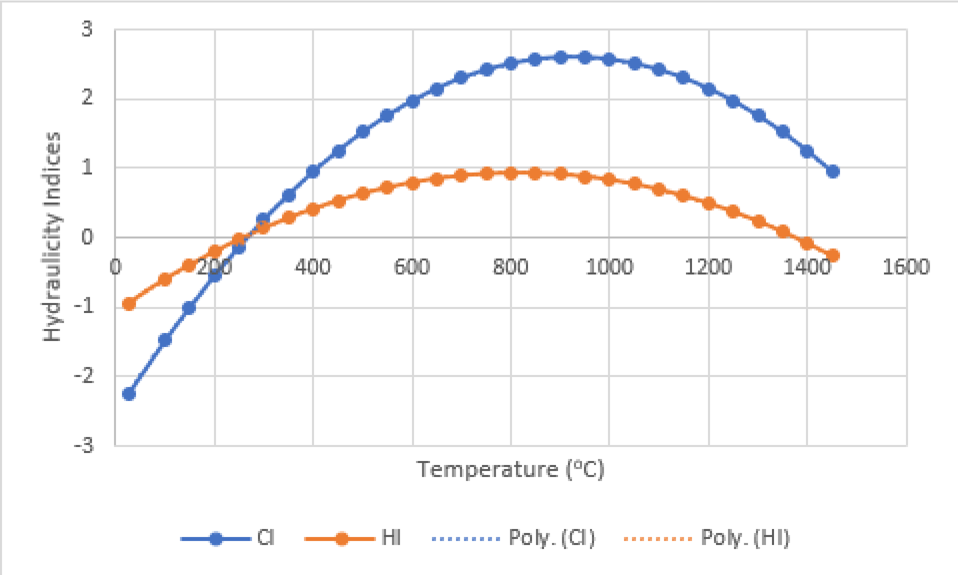

Figure 1: Effect of calcination temperature on the hydraulicity of periwinkle shell ash

Table 5: Input Data of calcination effect on PSA's hydraulicity

Temp (°C)	HI	CI		Temp (°C)	HI	CI
25	-0.94338	-2.25465		550	0.7235	1.7616
100	-0.604	-1.4784		600	0.796	1.9716
150	-0.3965	-0.9984		650	0.8535	2.1516
200	-0.204	-0.5484		700	0.896	2.3016
250	-0.0265	-0.1284		750	0.9235	2.4216
300	0.136	0.2616		800	0.936	2.5116
350	0.2835	0.6216		850	0.9335	2.5716
400	0.416	0.9516		900	0.916	2.6016
450	0.5335	1.2516		950	0.8835	2.6016
500	0.636	1.5216		1000	0.836	2.5716

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Table 6: Design variables and responses

Run	Factor 1 A: Temperature (°C)	Response 1 Hydraulic Index	Response 2 Cementation Index
1	500	0.636	1.5216
2	500	0.636	1.5216
3	1000	0.836	2.5716
4	25	-0.94338	-2.25465
5	250	-0.0265	-0.1284
6	1000	0.836	2.5716
7	500	0.636	1.5216
8	25	-0.94338	-2.25465
9	150	-0.3965	-0.9984
10	650	0.8535	2.1516
11	350	0.2835	0.6216
12	1000	0.836	2.5716
13	800	0.936	2.5116

Table 7: ANOVA for Response Surface Quadratic model for Hydraulic Index of PSA

Analysis of variance table [Partial sum of squares - Type III]

Source		**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model		5.59	2	2.79		
A-Temperature		*4.96*	*1*	*4.96*		
A^2		*1.19*	*1*	*1.19*		
Residual		0.000	10	0.000		
	Lack of Fit	*0.000*	*5*	*0.000*		
	Pure Error	*0.000*	*5*	*0.000*		
Cor Total		5.59	12			

Table 8: Coefficient of Regression for Hydraulic Index model of PSA

Std. Dev.	0.000	R-Squared	1.0000
Mean	0.32	Adj R-Squared	1.0000
C.V. %	0.000	Pred R-Squared	1.0000
PRESS	1.929E-011	Adeq Precision	

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PSA Hydraulic Index (HI) = -1.06 + 0.0049T – 0.000003T² $Eq. 3.0$

From Tables 7 and 8, the model as analyzed is quadratic having a coefficient of regression of 1. This implies the formation of an arc resulting from variations in calcination temperature. This arc is observed to have its crest around 800°C.

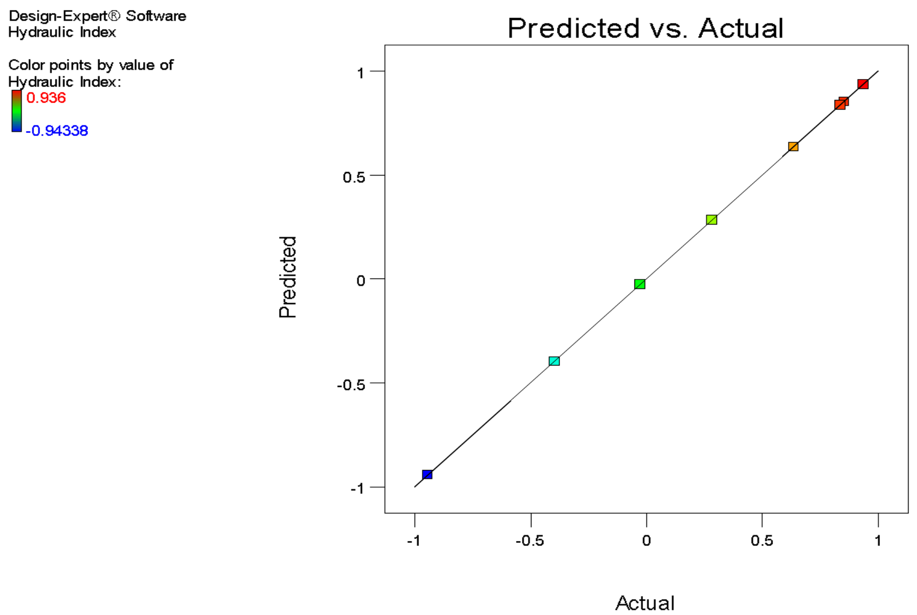

Figure 2: Model diagnostics for the hydraulic index of PSA

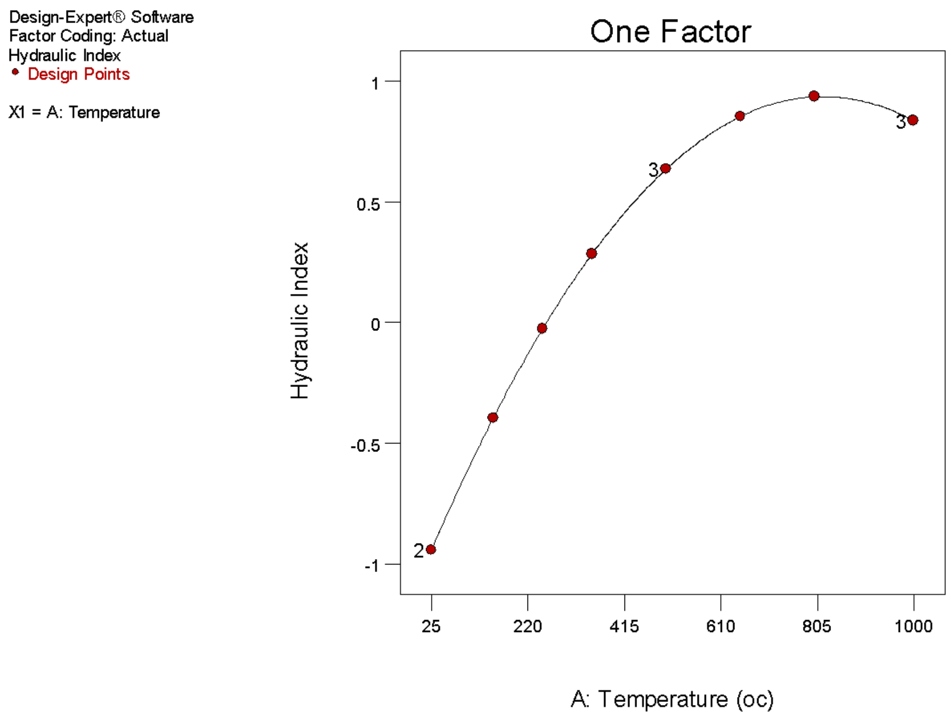

Figure 3: Modelled effect of calcination on the hydraulic index of PSA

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Table 9: ANOVA for Response Surface Quadratic model for Cementation Index of PSA

ANOVA for Response Surface Linear model Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	33.57	1	33.57	77.26	< 0.0001	significant
A-Temperature	*33.57*	*1*	*33.57*	*77.26*	*< 0.0001*	
Residual	4.78	11	0.43			
Lack of Fit	*4.78*	*6*	*0.80*			
Pure Error	*0.000*	*5*	*0.000*			
Cor Total	38.34	12				

Table 10: Coefficient of Regression for Cementation Index model of PSA

Std. Dev.	0.66	R-Squared	0.8754
Mean	0.92	Adj R-Squared	0.8640
C.V. %	71.83	Pred R-Squared	0.8172
PRESS	7.01	Adeq Precision	17.743

$$PSA\ Cementation\ Index\ (CI) = -1.525 + 0.0047T \qquad Eq.4.0$$

From Tables 9 and 10, the model can be said to be logically significant, having a confidence interval (P- value) much greater than 95% as well as a predicted coefficient of regression of 0.8172. Other statistical indices such as the deviation about the mean, the coefficient of variation, PRESS and adequate precision, collectively satisfy the logical arguments for a statistically sound model. This can be said to be same for the model obtained for the Hydraulic index of PSA as shown in equation 3.0.

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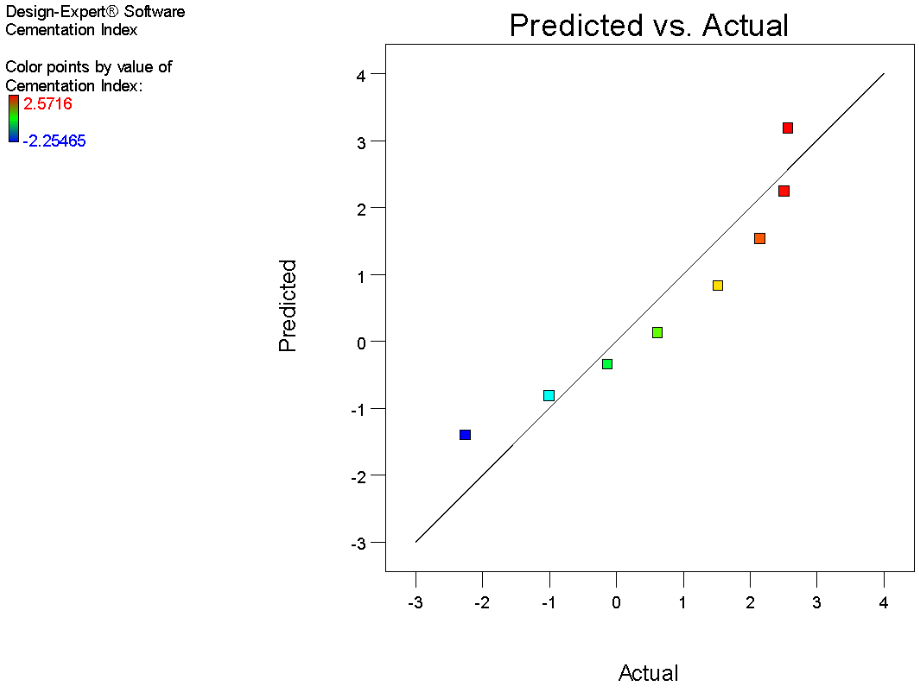

Figure 4: Model diagnostics for Cementation index of PSA

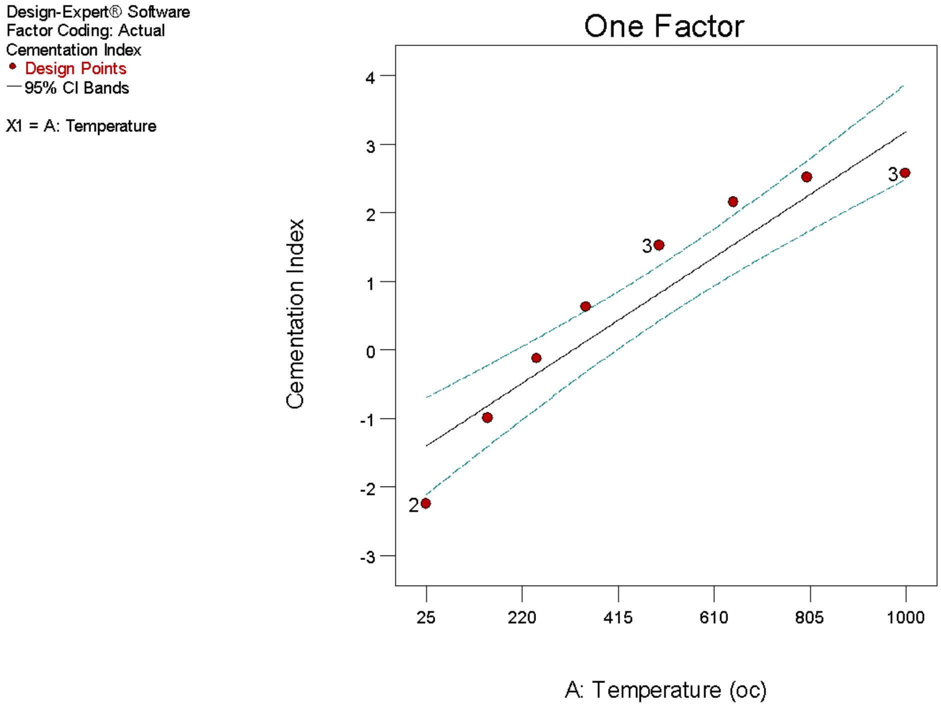

Figure 5: Modelled effect of calcination on the cementation index of PSA

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CONCLUSION

From the above investigation, the following sums up the research: Hydraulic index as well as cementation index are indices of binders and pozzolans relating directly to their compressive strength contribution in mortars and concretes. Similarly, both hydraulic and cementation indices of periwinkle shell ash were observed to be of a quadratic nature under the influence of varying calcination temperature with optimum results observed between 800 and 1000oC. Finally, Hydraulic and cementation indices are components of the oxide composition of the binder material, however, beyond compressive strength (which is favored directly with increasing HI and CI), other stability factors such as concrete or mortars resistance to harsh weather and chemical exposure conditions should be considered when choosing an optimum temperature for calcination.

Declaration of competing interest

We undertake not to engage in any financial, commercial, legal, or professional dealings with other organizations or the people we worked with that would have an impact on this research.

Credit authorship contribution statement

• Mac-Eteli, D. Happiness: Investigation, Writing - original draft.

• Nelson Tonbra Akari: Investigation, Writing - original draft.

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