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Short communication

Behavior of kernelrazzo floor finish in aggressive chloride environment

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ABSTRACT

The rising cost of building materials in Nigeria has made it necessary to source for cheaper and locally available materials to be used in construction. Palm kernel shell (PKS) obtained from the seed of oil palm tree in the western and southern part of the country is in great abundance in such quantity that it possesses environmental threat in waste management. In this paper, the behavior of floor finish made with PKS (termed Kernelrazzo) as a replacement for coarse aggregate was studied for thermal conductivity, water absorption and impact resistance by varying the percentages of PKS, marble chippings and granite dust. The concrete floor finish was exposed to 2.5–5.0% concentration of NaCl (Sodium Chloride) solution for seven days to simulate the expected service conditions of houses built along the coastline of the country. It was revealed that the thermal conductivity decreased as the percentage of PKS increases, the water absorption increased with increasing percentage of PKS while the impact resistance decreased with increasing percentage of PKS. The optimum replacement level of PKS was found to be 20% in combination with 30% granite dust and 50% marble chippings.

1. Introduction

Housing is one of the three fundamental human needs [1] and unaffordable housing has led to social inequality commonly observed in countries such as the United States of America [2]. Housing is a general term for shelter including the environmental condition of the building; the social services and other qualities of environment that contribute to making a community livable and comfortable environment.

The major challenge of accessibility to affordable housing is largely predicated on the colossal cost of conventional building materials, which accounts for 40–60% of the total construction cost of building projects [3] and this challenge could be mitigated using durable, economical, environmentally friendly and sustainable alternatives to expensive conventional building materials. Such non-conventional building materials include: rice husk ash, corncob ash and sawdust ash as cement replacement materials, and palm kernel shells as replacement for conventional coarse aggregates (gravel, granite stone, marble chippings, etc.) in concrete production and floor finishes [4].

Terrazzo is made from marble chippings, granite dust and cement as a floor finish because of its strengths, durability, aesthetic and thermal conductivity; however, the cost of its constituent's ingredient and own self weight which adds to the building total weight and cost makes its use limited. The alternative is to replace the marble chippings either partially or

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wholly with PKS which can reduce the cost of construction, lower dead weight on the building and lower cost of foundation because of lower dead load.

Olusola and Babafemi [4] conducted a series of tests to assess Kernelrazzo exposed to aggressive sulphate ($MgSO_4$), alkaline (NaOH) and acidic (H_2SO_4) environment and the effects of such environments on the compressive strength and surface deterioration. It was concluded that the acidic environment had the greatest impact on the compressive strength and surface deterioration. PKS concrete water absorption varies with the sizes of the PKS used in the concrete, but it is higher than concrete made from conventional aggregate because of its many pores [5]. Teo et al. [5] stated that the water absorption of PKS concrete also depends on the method of curing. For PKS concrete under air-dry curing, the average water absorption was 11.23% while for full water curing, was 10.64%. The water absorption which is a measure of permeability of the PKS concrete slows down after 28 days for full water curing condition. The thermal conductivity of PKS concrete was reported to be in the range of 0.05 and 0.69 $Wm^{-1}\,{}^{\circ}C^{-1}$ which is similar to concrete made from artificial aggregate as reported by [6,7], while the thermal conductivity of insulating mortar made from cement, lime and gypsum ranges from 0.07-0.1 $Wm^{-1}\,{}^{\circ}C^{-1}$.

The objective of this study is to evaluate the performance of Kernelrazzo floor finish in aggressive chloride environment based on its mechanical properties and thermal properties.

2. Experimental program

2.1. Materials

The Kernelrazzo constituents include cement, PKS, marble chippings, granite dust and water. The PKS and marble chippings used for this work were sourced in the cities of Ile-Ife and Ibadan, respectively. The PKS was pretreated with soap water to remove the leftover oil from the surface of the shell that may interact with the cement hydration and for proper binding in the cement matrix. After the pretreatment, the PKS was soaked in clean water for 5 h, to ensure that all the soap lather was completely removed, and thereafter sun dried for 7 days to remove excess moisture and then brought to saturated surface dry (SSD) condition. The PKS were screened to conform with aggregate gradation requirements of [8]. Granite dust which corresponds to the medium grading zone specified by [10] was sourced from a quarry along Ilesha-Ife road. The aggregates were graded to [9] as shown in Fig. 1 on their grading curves. The fineness modulus of the granite dust, marble chippings and PKS were 3.12, 6.93, and 6.88, with specific gravity of 2.42, 2.68, and 1.18, respectively. CEM I 42.5 N Ordinary Portland Cement (OPC) was used in this study with chemical composition and physical properties shown in Table 1.

2.2. Mixture design

The base mixture design for the Kernelrazzo used in this study is shown in Table 2. To evaluate the behavior of the Kernelrazzo in an aggressive environment, the mixture was divided into four groups based on the percentage content of granite dust with each group containing four sub-groups by replacing marble chippings with PKS. A 0.5 water to cement ratio was used without superplasticizer, to ensure adequate workability. A total of 48 (three samples per mix and curing age) slabs measuring 250 mm × 250 mm × 25 mm were prepared for impact resistance test, 48 cubes of 100 mm × 100 mm × 100 mm were prepared for water absorption test; and 48 cubes of 50 mm × 50 mm × 50 mm for thermal conductivity test.

2.3. Aggressive chloride environment

An aggressive chloride environment was selected in this study to replicate the exposure conditions usually found along the coastline of the western and southern part of Nigeria, like Lekki (6.4698 °N, 3.5852 °E), and Port Harcourt (4.8156 °N,

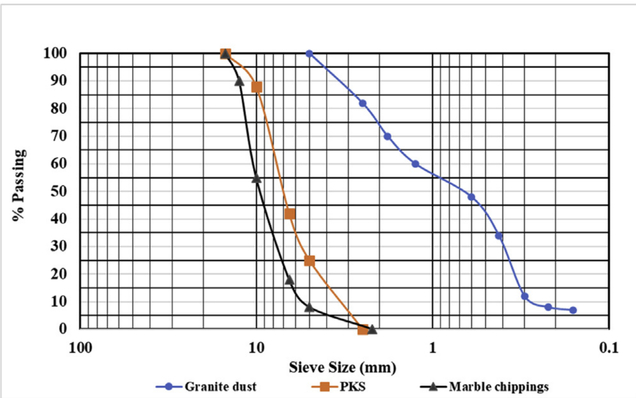

Fig. 1. Particle size distribution of the aggregates used.

Table 1
Chemical composition and physical properties of cement.

CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	SO_3 (%)	K_2O (%)	Na_2O (%)	MgO (%)	LOI (%)	Blaine cm^2/g	Density Kg/m^3
63.5	19.8	4.6	2.5	3.2	0.89	0.10	1.8	2.66	2680	3.15

Table 2
Design Mix Proportion.

Base mix proportion (100% MC + 0%PKS + 0% GD)								
Cement (kg/m^3)		Water (kg/m^3)		MC (kg/m^3)	PKS (kg/m^3)		GD (kg/m^3)	
363		181		1088	0		0	
Group	**Mix ID**	**MC (%)**	**PKS (%)**	**GD (%)**	**Mix ID**	**MC (%)**	**PKS (%)**	**GD (%)**
A	A1	100	0	0	A2	90	10	0
	A3	80	20	0	A4	70	30	0
B	B1	90	0	10	B2	80	10	10
	B3	70	20	10	B4	60	30	10
C	C1	80	0	20	C2	70	10	20
	C3	60	20	20	C4	50	30	20
D	D1	70	0	30	D2	60	10	30
	D3	50	20	30	D4	40	30	30

7.0498 °E). Three chloride concentrations of 0%, 2.5% and 5% were prepared by dissolution of anhydrous NaCl in equivalent potable water of 100 L volume equivalent to give the designated concentration. The chloride solution was stored in a curing tank specially prepared for this study till the testing date.

2.4. Mixing and specimen preparation

The batching of the Kernelrazzo constituents was done by weight and mixed in a rotating drum mixer thoroughly until a uniform mix was obtained without segregation nor bleeding. After mixing, representative samples from each batch were taken for slump test in accordance to [11]. As previously described, 100 mm × 100 mm × 100 mm cubes were prepared for compressive strength, water absorption and thermal conductivity while 250 mm × 250 mm × 25 mm samples were prepared for impact resistance. The specimens were kept at room temperature and covered with polythene sheets to prevent loss of moisture before demolding.

2.5. Curing and pre-conditioning

The specimens were moist cured under controlled environment for 28 days in accordance to [12] and later transferred to an aggressive chloride environment for another 28 days. Prior to mechanical testing, the samples were brought out of the conditioning chamber and air dried for 8 h to remove excess moisture on the surface that may impact on the test especially the compressive strength, impact resistance and thermal conductivity.

2.6. Testing of specimens

The specimens were tested for water absorption, compressive strength, impact resistance and thermal conductivity. The compressive strength test was conducted according to [12] using the 100 mm × 100 mm × 100 mm Kernelrazzo cubes.

The water absorption test was conducted per [13]. The water absorption calculated using Eq. (1), is a measure of the quantity of water the specimen can absorb at that curing age. The oven dried weight (W_{OD}) was obtained by heating the samples in an oven at 105 °C (as shown in Fig. 2) to a constant weight (overnight heating was done: 12–24 hours) to empty the pores of water and the saturated-surface-dry weight (WSSD) weight was obtained when all the pores were filled with water, without any film of water on the surface. In addition to absorption, the surface deterioration of the specimens was observed and visually rated according to rating summarized in Table 3, as suggested by [14] for concrete immersed in acidic solutions.

$$W_{abs} = \left(\frac{W_{SSD} - W_{OD}}{W_{OD}} X \ 100 \right) \% \tag{1}$$

The impact resistance test was carried out using the Schmidt hammer in accordance to [12] and the rebound number recorded. The specimens were brought out of the curing tank and allowed to drain off excess water for 12–24 hours and then tested using the Schmidt hammer.

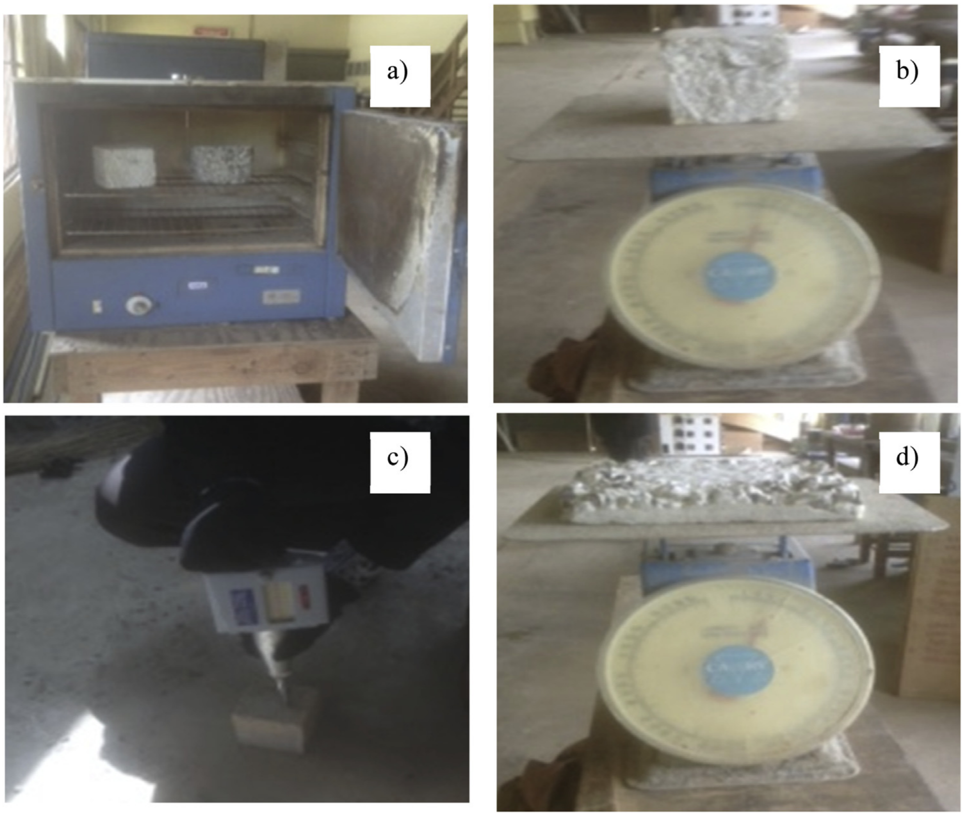

Fig. 2. Kernelrazzo (a) cubes in oven (b) measurement of cube specimen weight (c) cube being test for impact resistance (d) slab weight under measurement.

The thermal conductivity test was conducted on the Kernelrazzo samples using the Lee's disk apparatus based on the principle of equilibrium of heat loss by convection and heat gained by conduction. This test is suitable for materials with poor thermal conductivity. The Lee's disk apparatus as shown in Fig. 3 comprises of two disks of a known mass and specific heat capacity where the Kernelrazzo disk is inserted in between them. The upper disk temperature T_2 and the lower disk temperature T_1 were recorded with the aid of two thermometers inserted in the disks. The Kernelrazzo disk was removed and the lower disk was allowed to heat up to the upper disk temperature, T_2. The steam chamber was then removed, followed by the removal of the upper disk and replacing it with an insulator disk, so that the metal disk could cool to the room temperature. A cooling curve of the lower disk having a slope of dT/dt is plotted and the thermal conductivity of calculated from Eq. (2).

$$k = \frac{mc\left({}^{d}T/_{d}t\right)x}{A(T_2 - T_1)} \tag{2}$$

Where m is the mass of the metallic disk; A is the area of the Kernelrazzo disk in contact with the metallic disk, x is the thickness of the Kernelrazzo disk and c is the specific heat capacity of the lower disk.

Table 3
Deterioration Rating Scale [13].

Deterioration Level	Scale
No Attack	0
Very slight attack	1
Moderate Attack	2
Severe Attack	3
Very severe attack	4
Partial disintegration	5

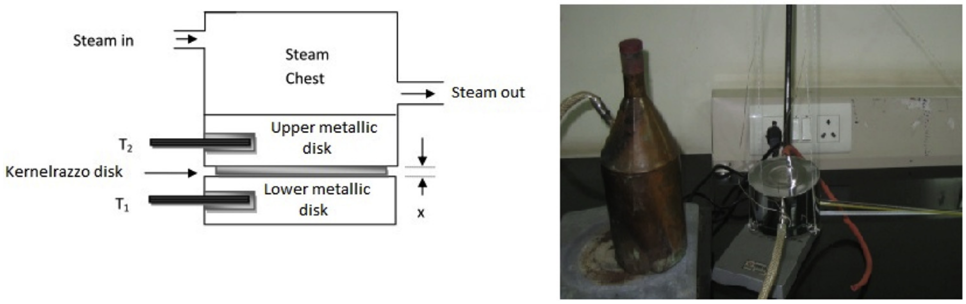

Fig. 3. Lee's disk apparatus for thermal conductivity measurement.

3. Results and discussion

3.1. Fresh properties test results

The workability of the Kernelrazzo was measured through a slump test by keeping the water-cement ratio constant at 0.5. The slump values are summarized in Table 3 and shown in Fig.4.

In group A, the addition of PKS led to the reduction of workability, with the highest reduction observed when the marble chipping was replaced up to 30% by PKS. In groups B, C and D, the introduction of granite dust (GD) to the mix where MC has been replaced with PKS resulted in further reduction of workability. The workability for all the mixtures could be improved by adding viscosity modifying agent (VMA) like superplasticizer. Overall, both GD and PKS resulted in lower workability.

The reduction of workability could be explained by the aggregate geometry and physical properties. The PKS aggregate has irregular shapes like irregular flaky, angular circular and polygonal [15]; which depends on the mode of crushing of the oil palm seed, will inhibit the flow of the freshly mixed Kernelrazzo and resulted in lower slump values. On the other hand, the granite dust has a rough and angular texture with high specific area. The high specific area requires higher moisture for wetting of the aggregate thereby reducing the water required for flow of the matrix. The combination of rough texture, angular and irregular shape result in higher friction between the aggregate and the cement paste which is noticeable by low workability of the Kernelrazzo. Similar results have been reported by different authors [4,16,17] when PKS was used as replacement for coarse aggregate in concrete.

3.2. Mechanical properties

3.2.1. Compressive strength

The compressive strength of the specimens presented in this section is divided into sub groups to evaluate the effect of granite dust; PKS; and aggressive chloride environment.

In specimens without PKS conditioned at 0% chloride environment, the compressive strength increased with increasing percentages of granite dust (GD) as shown in Table 3 and Fig. 5(a). The granite dust having particle sizes much smaller than the marble chippings act as fillers by filling the voids between the aggregates of the marble chipping resulting in a denser microstructure evidence by higher compressive strength.

When PKS was used to replace MC, a decrease in the compressive strength was observed. At a higher percentage the PKS, because of its size, creates more voids within the composite matrix which results in a lower compressive strength as reported by [4,18,19]. The compressive strength of concrete depends on the strength of its constituent aggregate, and the cement paste depending on the one that fails first of the two. Based on this, the strength of PKS and its thickness are lower than the corresponding marble chipping which results in lower compressive strength.

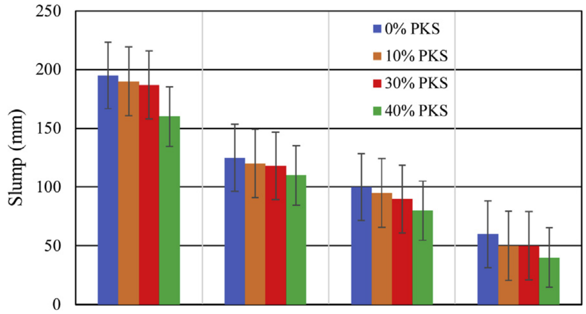

Fig. 4. Slump test result of freshly mixed Kernelrazzo.

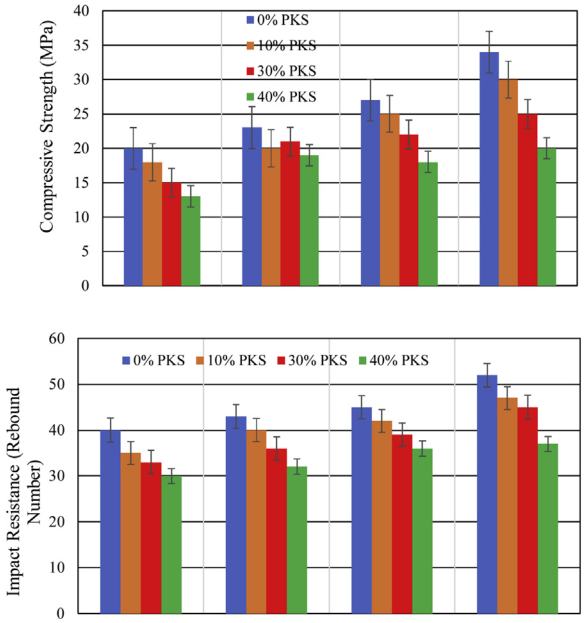

Fig. 5. 28th day compressive strength. (upper) and Impact resistance (lower) of specimens cured in 0% chloride solution.

The properties of Terrazzo are summarized in Table 7. Comparison of the minimum compressive strength results recommended by [11] with those obtained in this study as shown in Table 2, implies that the PKS can be used as a replacement for MC in the presence of granite dust (group D mixtures).

3.2.2. Impact resistance

The effect of palm kernel shell and granite dust contents on the impact resistance of Kernelrazzo specimens is presented in Table 3 and Fig. 5(b). The impact resistance of Kernelrazzo decreased with increase in palm kernel shell content, but increases with granite dust content, though the rate of decrease/increase varies according to the level of palm kernel shell and granite dust contents. It was observed that at every level of combination of Kernelrazzo constituents, the incorporation of granite dust recorded an average of 2.6% increase in impact resistance.

It has been reported that the aggregate impact value of PKS ranges between 6.00 and 7.51% [20,21], which means it has good absorbance to shock when compared to other normal weight aggregates (crushed stone). In view of this, it is expected that the impact resistance of Kernelrazzo should increase with an increase in percentage PKS, but this was not so. The behavior of aggregates in concrete is a compound expression of concrete as a composite material, but not just the individual characteristics of its constituents. The aggregate-cement paste bond contributes largely to the resistant of concrete to impact

Table 4
Fresh, thermal and mechanical properties of Kernelrazzo.

Group	Mix ID	Slump (mm)	Moisture Absorption (%)	Deterioration rating	Compressive Strength (in 0% chloride solution) (N/mm^2)	Impact Resistance (in 0% chloride solution) (Rebound Number)	Thermal conductivity (exposed to 0% chloride) (W/mK)
A	A1	195	6.0	0	20	40	1.82
	A2	190	7.0	0	18	43	1.66
	A3	187	7.0	0	15	45	1.48
	A4	160	7.5	0	13	52	1.30
B	B1	125	6.5	0	23	35	1.91
	B2	120	7.0	0	20	40	1.71
	B3	118	6.5	0	21	42	1.63
	B4	110	7.0	0	19	47	1.49
C	C1	100	4.5	0	27	33	1.93
	C2	95	5.0	0	25	36	1.76
	C3	90	5.0	0	22	39	1.66
	C4	80	5.0	0	18	45	1.51
D	D1	60	3.0	0	34	30	1.98
	D2	50	3.5	0	30	32	1.81
	D3	50	4.5	0	25	36	1.70
	D4	40	4.0	0	20	37	1.55

much more than its aggregate constituents in the absence of reinforcing fibers [22,23]. This might have been the reason for the decrease in the impact resistance of Kernelrazzo with increase in percentage of palm kernel shell content. However, the incorporation of granite dust increased the impact resistance of Kernelrazzo specimens with an increase in granite dust content. This is due to the increase in compressive strength of terrazzo by incorporating granite dust, which in turn increased the impact resistance, penetration shear failure and tensile fracturing [24,25].

3.2.3. Thermal conductivity

The thermal conductivity of a material is the ability of the material to conduct heat. It is desirable for a concrete floor system to have a low thermal conductivity value which makes it behave as an insulator to heat for the building occupants. The thermal conductivity of concrete depends on its density and the pores within the concrete matrix [26]. The thermal conductivity of PKS concrete was 0.45 W/mK, while it was 0.19 W/mK for PKS [26].

As shown in Table 3 and 5, the thermal conductivity of Kernelrazzo decreases with an increase in PKS content, and it increased with an increase in granite dust content. Increase in PKS content decreased the Kernelrazzo density which resulted in lower thermal conductivity. the observed behavior due to granite dust on the thermal conductivity is because it densifies the microstructure of the Kernelrazzo. Therefore, Kernelrazzo with higher PKS content is preferable over the one with higher granite dust based on thermal conductivity property.

3.2.4. Water absorption

The effect of PKS content and curing age on the water absorption of Kernelrazzo specimens continually is presented in Table 3. The water absorption was decreased with curing age in all curing media (water, and chloride solution). However, the curing media influenced the degree to which the curing age affected the water absorption. At lower chloride concentration, the absorption was higher for all the specimens regardless of curing age and mix proportion. The water absorption which is a measure of the specimens' permeability largely depends on the pore microstructure.

The effect of curing on absorption can be explained by the microstructure of the Kernelrazzo specimens. The formation of an internal conduit of pores in concrete facilitates suction pressure, which in turn determines water absorption capacity of concrete. During curing by immersion in water, concrete gains strength via hydration of cement paste and fills the microstructural pores within it with hardened cement paste thereby reducing water absorption. This process is known as hydration [27,28]. Therefore, with increase in curing age of concrete in water, there is a decrease in water absorption due to the densification of the microstructural pores with hardened cement paste. This process could have been responsible for the decrease in water absorption of Kernelrazzo specimens cured in water with increase in curing age.

The increase in water absorption of the Kernelrazzo slab specimens cured in chloride environment could have been caused by the deteriorating effect of chloride, which involves the disintegration of hardened cement paste to enhance passage of fluids through its microstructural pores via permeability [29].

3.3. Effect of chloride on properties of kernelrazzo

3.3.1. Compressive strength, impact resistance and thermal conductivity

The effect of chloride environment on the compressive strength of Kernelrazzo is summarized in Tables 4 and 5 and Fig. 6 and 7. From the Tables, higher chloride concentration has higher negative influence on the compressive strength of the specimens. The compressive strength of Kernelrazzo specimens exposed to aggressive chloride environment was dependent on the exposure duration, mix constituent and the concentration of the conditioning medium. At 28 days conditioning, the

Table 5
Summary of Specimens exposed to 2.5% Chloride Solution.

Group	Mix ID	Moisture Absorption (%)	Deterioration rating	Compressive Strength (N/mm^2)	Impact Resistance (Rebound Number)	Thermal conductivity (W/mK)
A	A1	7.0	4	17	28	1.73
	A2	7.0	3	16	32	1.58
	A3	7.5	4	14	34	1.31
	A4	7.5	4	11	43	1.23
B	B1	6.0	2	21	26	1.85
	B2	6.5	3	21	29	1.69
	B3	6.5	2	19	31	1.56
	B4	7.0	3	14	38	1.03
C	C1	5.0	2	25	24	1.79
	C2	4.5	2	23	29	1.65
	C3	4.5	1	20	27	1.53
	C4	4.0	1	16	36	1.4
D	D1	3.0	1	32	25	1.83
	D2	3.0	0	29	24	1.73
	D3	3.5	2	23	29	1.57
	D4	4.0	1	16	28	1.47

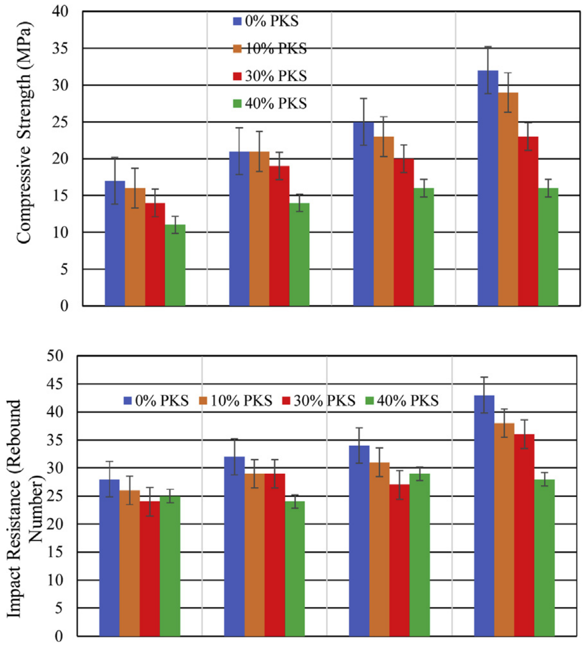

Fig. 6. Compressive and Impact Resistance strength of specimens exposed to 2.5% chloride solution.

effect of the curing medium on the impact resistance of Kernelrazzo specimens became more pronounced. This trend was most likely due to the increase in compressive strength of concrete with increase in curing age when cured in water because of hydration of cement; and the decrease in compressive strength of concrete with increase curing age when cured in chemically aggressive medium.

Specimens having higher PKS content and lower content of GD suffered the highest reduction in compressive strength.

As observed in the compressive strength, a similar trend was observed in the impact resistance behavior of the specimen when exposed to aggressive chloride environment. The same specimen with highest loss of compressive strength also displayed the highest loss of impact resistance as shown in Table 6. The impact resistance of concrete has been largely directly linked to its strength formation due to cement hydration. In view of this, as curing age of Kernelrazzo specimens

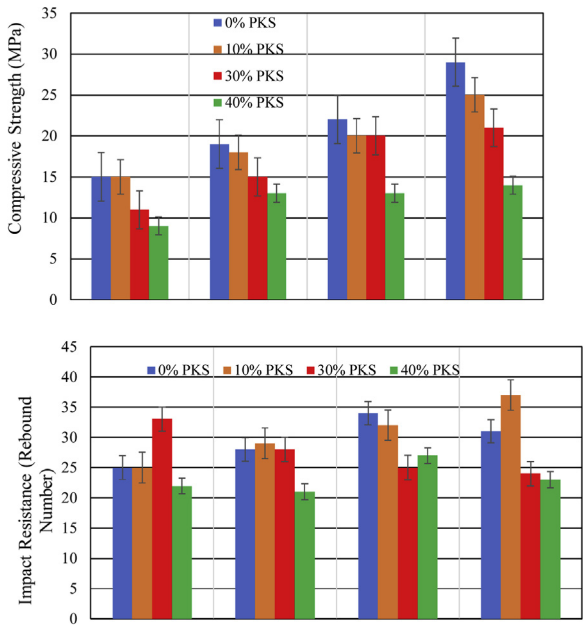

Fig. 7. Compressive strength and impact resistance of specimens exposed to 5% chloride solution.

Table 6
Minimum Requirement for Terazzo Floor Finish.

Technical Characteristics	Testing Method	Requirement
Compressive Strength	BS EN ISO 13,748-1: 2004 [30]	25 – 45 N/mm^2
Water Absorption	BS EN ISO 13,748-1: 2004 [30]	Less than 5%
Impact Resistance	BS EN 12504-2: BSI: 2012 [14]	20 – 45 N/mm^2

cured in water increased, impact resistance also increased. However, the case of specimens conditioned in chloride environment resulted in decrease in impact resistance with increase in curing age [31].

Table 7
Summary of result for Specimens exposed to 5.0% Chloride Solution.

Group	Mix ID	Moisture Absorption (%)	Deterioration rating	Compressive Strength (N/mm^2)	Impact Resistance (Rebound Number)	Thermal conductivity (W/mK)
A	A1	6.5	5	15	25	1.44
	A2	7.0	5	15	28	1.28
	A3	7.5	4	11	34	1.12
	A4	7.5	4	9	31	1.08
B	B1	6.5	4	19	25	1.68
	B2	6.0	4	18	29	1.59
	B3	6.0	4	15	32	1.37
	B4	6.5	2	13	37	1.25
C	C1	5.5	3	22	33	1.68
	C2	5.0	3	20	28	1.55
	C3	4.5	3	20	25	1.42
	C4	4.5	2	13	24	1.25
D	D1	4.0	2	29	22	1.72
	D2	4.5	2	25	21	1.56
	D3	4.5	2	21	27	1.44
	D4	4.5	2	14	23	1.37

The thermal conductivity of Kernelrazzo specimens decreases with higher chloride concentration, higher PKS content and GD content as shown in Tables 4 and 5. Comparison of the specimens conditioned in chloride environment with those that are not exposed showed that the presence of chloride ions in the specimens alter their thermal conductivity. The reduction can be because of chloride attack on the Calcium Silicate Hydrate (CSH) gel produced during hydration which damaged the pores microstructure. This chloride attack is evident by the physical degradation observed on the specimens as summarized in Tables Table 44, Table 55 and Table 77. Specimens with 50% PKS content conditioned at 5% chloride for 56 days displayed the highest deterioration in form of scaling and disintegration as shown in Fig. 7b.

4. Conclusions

In this study, the behavior of Kernelrazzo in an aggressive chloride environment was evaluated and reported. The chloride environment was simulated by different chloride concentration solutions and the specimens conditioned for 28 days. Based on the observed and presented results, the following conclusions can be drawn:

- At 20% content of PKS and GD, the workability of freshly mixed Kernelrazzo reduced by 15–45%, but to maintain the water to cement ratio, a high range water reducing agent would be required to achieve specified workability.
- The thermal conductivity of Kernelrazzo in chloride environment increased by 25–35% with 25% increase in granite dust content. However, a 30% decrease was observed at 30% increase in palm kernel shell content.
- The water absorption of Kernelrazzo in a chloride environment decreased by 10–25% with an increase in granite dust content, but it increased at higher the PKS content (20–40% content). Water absorption of concrete has been reported to be dependent on compressive strength and void volume in concrete. The higher the palm kernel shell content, the lower the compressive strength and the higher the water absorption.
- The impact resistance of Kernelrazzo increased by 20–35% with an increase in percentage granite dust but decreased with an increase in percentage PKS content of the total aggregate weight. The impact resistance of concrete therefore depends on the compressive strength of the Kernelrazzo. The addition of granite dust into Kernelrazzo acts as a filler of the interstitial space within it, which increased the compressive strength.
- The performance of Kernelrazzo in an aggressive chloride environment depend on the concentration of the chloride environment. Impact resistance decreased, while water absorption increased with increase in concentration of curing media from 2% to 5%. This could be due to the formation of Friedel's salt ($3CaO.Al_2O_3.CaCl_2.10H_2O$) chloride reacts with hardened cement paste. The chemical structure of Friedel's salt has been reported to be weaker and softer.

- Based on this experimental study, the optimum mix design for Kernelrazzo that satisfies the requirement of BS EN ISO 13,748 – 1: 2004 [30] for terrazzo floor finish is 30% granite dust content having 20% palm kernel shell and 50% marble chippings.

Conflict of interest

The authors declare no conflict of interest.

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