Case Studies in Construction Materials 15 (2021) e00568

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Effects of calcined clay, sawdust ash and chemical admixtures on Strength and Properties of concrete for pavement and flooring applications using Taguchi approach

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ARTICLE INFO

Keywords:
Abrasion
Skid resistance
Strength
Calcined clay
Sawdust ash
Pavement concrete
Chemical admixture

ABSTRACT

Strength, abrasion and skid resistance are crucial factors for assessing the performance of pavement concrete and concrete for flooring applications. Due to sustainability concerns and global climate change, various supplementary (pozzolanic) cementitious materials (SCMs) are increasingly promoted for use as cement replacement in pavement concrete without considering their effects on the strength, abrasion and skid resistance. In addition, chemical admixtures are often added to improve workability of pavement concrete. Therefore, this study investigates the effects of calcined clay and sawdust ash utilized as cement replacements and two kinds of chemical admixtures on thestrength, abrasion and skid resistance of concrete for pavement and flooring applications. Calcined clay is preferable to sawdust ash as partial cement replacement in pavement concrete as it gives higher flexural strength, skid resistanceand similar abrasion value. However, sawdust ash is preferable for flooring applications owing to its lower water absorption and higher compressive strength. The optimum calcined clay is 5% while the optimum crystalline-based admixture is 1%. More studies are required to guide correct applications of SCM in sustainable concrete pavement.

1. Introduction

Skid resistance of pavement is crucial for aircraft landing and vehicular braking [1,2]. However, with frequent usage, the surface of such pavements become worn-out due to friction, thereby increasing the loss of braking force as well as increase risk of poor control.

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https://doi.org/10.1016/j.cscm.2021.e00568
Received 12 January 2021; Received in revised form 4 March 2021; Accepted 4 May 2021
Available online 10 May 2021
2214-5095/

Skid resistance performance of pavement is a function of surface texture, material properties as well as dry/wet condition of the pavement. A recent study confirmed that skid resistance performance of a pavement is influenced by the material properties/composition comprising the pavement [2]. Cement loss when pavement ages as well as attenuation of texture of exposed pavement aggregates due to polishing effect decreases skid resistance of pavement before the end of their service life [1]. Therefore, appropriate cement type, mixture design and constituent materials are essential to improve skid resistance of pavements and ensure favourable long-term performance. In addition, careful selection of coarse aggregates and increased number of lanes in pavement construction are important for improve skid resistance [1]. Optimizing the mixture designs of pavement to accomplish conflicting mechanical, environmental and safety requirements is essential to ensure a cost-effective sustainable, multi-functional pavement [3]. Unfortunately, cement concrete pavement has high noise pollution and poor skid resistance due to its rigid, smooth and compact structure, low adhesion and insufficient macrotexture [4]. Likewise, another study recommended balancing the surface abrasion resistance, mechanical strength, surface abrasion resistance and freezing resistance of concrete pavements to determine the supplementary cementitious materials (SCM) to be added and their dosage [5]. Some studies reported that the abrasion resistance of concrete pavement is affected by the surface texture, water-cement ratio, SCM type and combination [6,7]. The studies reported that a decreased in abrasion resistance with increase in water-cement ratio, increases with compressive strength and use of fibre and that silica fume yields better wear resistance than fly ash [6–9]. In addition, there is insufficient studies on the safety aspect (skid resistance) of rigid concrete pavements.

A recent study revealed that pavement skid resistance is influenced by maximum aggregate size, binder, aggregate gradation and air voids content [10]. Skid resistance is the force that develops when a vehicle tire slides along the pavement surface during the braking maneuver and this force comprises two mechanisms namely adhesion and hysteresis. While adhesion is an intermolecular force between vehicle tire and surface microtexture, on the other hand, hysteresis on macrotexture surface level, occurs as a result of energy loss due to the bulk deformation of vehicle tire in contact with surface texture asperities [11]. A recent study revealed that skid resistance is mainly affected by average annual daily traffic, surface layer material, number of lanes and polished stone value [12]. The authors reported that skid resistance is not affected by pavement type and thickness and frequency of rehabilitation. Mitigation of deterioration of skid resistance and texture of road surface becomes important to reduce road accidents and improve safety of roads [13]. Risks of road accidents can be minimized by 50 % bydoubling skid resistance of pavements [14]. A recent study revealed that nano-montmorillonite, nano-silica, and nano-halloysite improved skid resistance of concrete pavement (BPN) by 24 %, 18.9 %, and 9.7 % when utilized as partial substitution of cement [15]. The authors reported that montmorillonite improved adhesion and that skid resistance can be improved with improved permeability of concrete pavement and recommended optimal cement replacement with 2% nano-montmorillonite, 3% nano-silica, and 3% nano-halloysite by weight of cement. Another study also reported that continuously graded aggregates provide better skid resistance compared to single-sized aggregate mixture because of its higher friction coefficient [16].

There have been calls to develop wear-resistant concrete but no affordable concrete has been developed. Since the abrasion occurs at the surface, the quality and strength of cement is a crucial factor. The abrasive resistance of concrete depends on paste hardness, type of aggregate and strength of aggregate/paste bond and the amount of calcium hydroxide in the hardened paste which depends on the water-cementitious ratio used in the concrete [17]. Abrasion resistance is the resistance of concrete surface under shear force and it is a crucial parameter to maintain skid resistance and surface texture of concrete pavement [15]. Another study reported that limestone concrete showed less damage compared with the river gravel concrete mixture after freeze/thaw cycles and also recommended surface treatments [18]. Also, a recent study recommended artificial aggregates, surface water drainage by grooving and inclusion of synthetic fibres enhanced not only the micro/macrotextures of pavements nut also improved their skid resistance [19]. In addition, the authors utilized PFA (pulverized fly ash) and microsilica sand as cement replacement as well as HRWRA (high range water reducing admixture). Therefore, the authors called for selection of suitable raw materials, mix design and mix sequence in concrete pavements to reduce rehabilitation frequency and extend service life of concrete pavements.

Abrasion susceptibility of highway pavements has a great impact on the skid resistance, and consequently accident rate. Abrasion is due to surface poor curing and loss of integrity due to texturing and to reduce abrasion, the authors called for appropriate texturing of concrete pavements [20]. Porous asphalt surfaces demonstrate higher skid resistance compared to dense asphalt concrete and are more resilient to adverse conditions such as rainfall intensity and increasing vehicular speed [21]. Likewise, the authors also reported that higher cross slopes provide better safety against skidding irrespective of surface type. Another study reported that roller compacted concrete with improved skid resistance can be achieved with 17.20 % by volume substitution of fine aggregate with crumb rubber and 1.87 % nano silica addition by weight of cementitious materials [22].

The performance of concrete for whatever application is dependent on certain properties of this material either in the fresh of hardened state. Properties in the fresh state is determined by workability while in the hardened state concrete performance can be accessed in form of mechanical strength and durability properties. Concrete pavements are designed and built with the ultimate aim of ensuring that the transmitted stresses due to wheel load are sufficiently reduced to a safe value on the sub-grade soil; to fulfill this requirement, concrete pavements should be strong enough and stable [23]. Furthermore, since strength is an indicator of concrete quality, therefore, it is vital to understand the strength behavior of concrete pavements that forms this basic requirement [24]. Therefore, developing concrete mixture in order to improve the concrete strength will results to higher performance concrete pavement [25].

Sawdust ash (SDA), also known as wood waste ash (WWA), has been reported useful in reducing ASR (alkali silicate reactivity) and electrical conductivity, reduce cracking susceptibility and weight loss in aggressive environment, improve compressive strength and workability due to lower water demand and reduces water absorption of concrete materials due to its pozzolanic and filler characteristics [26]. In addition, though several studies have reported the performance of crystalline-based admixtures (CBA) in concrete, there is still insufficient investigation on the effectiveness of CBA as self-healing in concrete for pavement and flooring applications [27–30]. The long-term self-healing properties of CBA is useful in pavement which is susceptible to repeated cracking and recovery [31]. Therefore, this study aims to investigate the effect of calcined clay, saw dust ash as cement replacement as well as chemical admixtures on concrete for pavement and flooring applications. The study is significant as it contributes towards sustainability and cleaner production by lowering carbon emission through cement replacement and reduction of hazardous waste disposal of sawdust. The study is also significant by showcasing correct application of chemical admixtures in pavement concrete and concrete for flooring applications, which is scarce in literature.

2. Materials and methods

2.1. Materials

The cement used in the study was grade 42.5R Dangote brand of Portland limestone cement available in the local market. The saw dust was sourced from a saw-mill industry in Ikere-Ekiti, Ekiti state in Nigeria. The saw dust was burnt to ashes by open burning in a metal container. The ash was sieved through 150 mm sieve size. The clay was sourced locally from Ire Clay Production Limited Company in Ire town, Ekiti State, Nigeria. It was moulded into 150 mm diameter balls and dried for two weeks. This was done to remove the moisture and to make it easy for firing. After drying, the clay balls were laid on crucibles and placed in a muffle furnace for calcination at 900 °C for 2 h before Pulverization. The calcined clay was sieved through 150 mm sieve size.The fine aggregate used was stone dust. It was sourced from an on-going construction site outside the Ekiti State University (EKSU) campus, Ado Ekiti, Ekiti State. The coarse aggregate passing through sieve size 10 mm and 20 mm also sourced from an on-going construction site outside EKSU campus. Two types of chemical admixtures were utilized in this study namely the crystalline-based admixtures (CBA) and super-plasticizer and both were manufactured by the same company named Advanced Concrete Technology Limited, located in Ikeja, Lagos State, Nigeria. CBA is hydrophilic in nature and react with the constituents of the cement matrix to form CSH crystals. These crystals generate pore shrinking deposits that are found to improve the concrete's ability to resist water penetration.Potable water obtained on campus was utilized in concrete mixing.

2.2. Methods

Taguchi experimental design was utilized in this study. The factors and levels of each experimental components are displayed in Table 1 while the orthogonal array utilized in conducting the experiment is shown in Table 2. The mix proportion of the concrete is depicted in Table 3. Ref. [32] recommended the use of 5% saw dust ash as partial cement substitution for maximum strength benefit. The same percentage replacement was replicated for calcined clay to ensure uniformity in percentage of SCM addition. Ref. [33] achieved reduced water absorption for conventional concrete using 2% (by weight of cement) of crystalline protection materials. The study considered a variation in Crystaline based admixture between 0% and 2% by weight of cement. The super plasticizer dosage was also varied within 0% and 2% to evaluate influence of super plasticizer on the workability.The chemical composition of both calcined clay and sawdust ash is displayed in Table 4. The pozzolanic content ($SiO_2 + Al_2O_3 + Fe_2O_3$) of calcined clay of 82.72 % is greater than 70.33 % recorded for sawdust ash and meets the minimum requirement of 70 % for pozzolanic materials [36]. This implies both calcined clay and sawdust ash can be employed as cement replacement in concrete.

2.3. Testing

Workability was measured using a slump cone of bottom diameter 200 mm, top diameter 100 mm and height 300 mm. The test was done in accordance to BS EN 12350- 2:2009.

The abrasion test was carried out on cubes using an abrasion testing machine displayed in Fig. 1(a) while abrasion tested samples are displayed in Fig. 1(b). The initial weight of each specimen was recorded before placing in the machine and after 500 revolutions the samples were remove from the machine and weighted. The percentage weight loss was computed for each trial mix using Eq. (1)

$$\frac{W_2 - W_1}{W_1} \times 100 \tag{1}$$

W_1= Initial weight of test specimen (g)

Table 1
Factors and their variation level.

Level	Factor			
	Calcined clay Replacement of cement (%)	Saw Dust Ash (SDA)	Crystalline based Admixture (CBA) Addition (% wt of cement)	Super Plasticizer (SP)
1	0	0	0	0
2	2.5	2.5	1	1
3	5	5	2	2

Table 2
L_9 (3^4) Orthogonal array for conducting design of experiments.

Mix	Parameter			
	%Replacement of cement by weight		Addition (% wt of cement)	
	Calcined clay	SDA	CBA	SP
1	5	5	1	0
2	5	2.5	0	2
3	5	0	2	1
4	0	2.5	1	1
5	2.5	0	1	2
6	2.5	5	0	1
7	2.5	2.5	2	0
8	0	5	2	2
9	0	0	0	0

Table 3
Mix proportion of constituent material.

Mix	Cement (kg/ m^3)	%Calcined clay (kg/ m^3)	%SDA (kg/ m^3)	% CBA (kg/ m^3)	% SP (kg/ m^3)	FA (kg/ m^3)	Coarse Aggregate	
							0–10 mm (kg/ m ^{3})	10–20 mm (kg/ m^3)
1	364	18.2	18.2	3.64	0	764	562	562
2	364	18.2	9.1	0	7.28	764	562	562
3	364	18.2	0	7.28	3.64	764	562	562
4	364	0	9.1	3.64	3.64	764	562	562
5	364	9.1		3.64	7.28	764	562	562
6	364	9.1	18.2	0	3.64	764	562	562
7	364	9.1	9.1	7.28	0	764	562	562
8	364	0	18.2	7.28	7.28	764	562	562
9	364	0	0	0	0	764	562	562

SDA- saw dust ash; CBA-crystalline based admixture; SP-superplasticizer; FA- Fine aggregate.

Table 4
Chemical composition of calcined clay and sawdust ash.

Oxides	Calcined clay [34]	Sawdust ash [35]
SiO_2	53.4	53.39
Al_2O_3	22.75	14.30
Fe_2O_3	6.57	2.64
MgO	0.49	3.30
CaO	0.10	7.20
P_2O_5	0.06	2.95
K_2O	0.15	8.43
TiO_2	0.03	0.05
Na_2O	1.97	1.00
MnO	0.05	0.41
LOI	4.83	5.48

W_2= Final weight of test specimen (g)

Skid resistance test was carried out to determine the energy loss when a rubber slides edge is propelled over the nine trial mixes of the hardened concrete obtained in the study. The skid resistance experimental set up is portrayed in Fig. 1(c). The test was carried out using a skid resistance tester and the values obtained represents the frictional properties and is expressed in British Pendulum Number (BPN). In addition, split tensile strength test was performed using universal testing machine displayed in Fig. 1(d) according to BS EN 12390-6:2009 at 28-day. Load was centrally applied on the specimen and was gradually increased until failure occurred by splitting. The horizontal tensile stress was calculated using Eq. (2) as follows:

$$F_t = \frac{2P}{(\pi DL)} \tag{2}$$

where P = The maximum load; D = Diameter of the cylinder concrete; L = Length of the cylindrical concrete; F_t = Split tensile strength (MPa).

(a) (b)

(c) (d)

Fig. 1. (a) Abrasion equipment (b) Some samples after abrasion test (c) Sample undergoing Skid resistance test (d) Split tensile strength test with Universal Testing Machine.

Furthermore, flexural strength which is a degree of the tensile strength of an unreinforced concrete beam or slab to resist failure in bending was carried out accordingto BS EN 12390-5: 2009.Three-point loading point method was used, to carry out flexural strength on a beam of size (400 mm by 100 mm by 100 mm) at 28-day. The flexural strength was determined using Eq. (3):

$$\mathrm{FL} = \frac{3PL}{2\mathrm{BD}^2} \tag{3}$$

Where; P = max load measured (kN), D = Depth (mm), L = Effective length(mm), B = Width (mm), and FL = Flexural Strength (N/mm^2)

Water absorption test was used to measure the amount of water absorbed under specified conditions. The concrete after curing for 28 days were oven dried at temperature of 105 °C for 6 h, immediately weighed and subsequently wholly immersed in water for 24 h and weighed again. Eq. (4) was used to estimate the percentage water absorption

$$\text{Water absorption} = \frac{W_2 - W_1}{W_1} \times 100 \tag{4}$$

where W_1= Weight of sample before immersion in water; W_2= Weight of sample after immersion in water

3. Results and discussion

3.1. Workability

The results of workability, which is an important parameter in the determination of concrete performanceare shown in Figs. 2 and 3 . Fig. 2 indicates that the slumpvalue decreases as the SDA content increases. In contrast, there was a decrease in slump up to 2.5 % increment in CC and an increased afterwards. As reported by [32], the high demand of water with increase in SDA is due to increase in the amount of silica in the mixture. Also, as revealed in Fig. 3, there was a decreased in the slump with the increased in SP proportion up to 1% and increased in afterwards; indicating that SP proportion up to 2% enhanced the workability of the mix. Therefore, replacement of cement by 5%CC with 2.5 %SDA will required SP dosage up to 2% to compensate for the workability.In addition, Fig. 3 indicates that CBA content of 2% corresponds to a reduction in slump which translates to a low moisture content. Previous research on the application of CBA in concrete has indicated that low moisture content is required to achieve adequate dosage and good penetration [33].

3.2. Water absorption

Water absorption of the concrete mixtures were observed to increase with the increase in calcined clay as shown in Fig. 4. Experiment run 2 containing 5% calcined clay (CC) and 2.5 % SDA (sawdust ash) replacement of cement recorded the highest water absorption of 7.21 % as shown in Table 5. On the other hand, concrete water absorption increased with SDA up to 2.5 % cement replacement and decreased significantly to 4.75 % thereafter. This implies SDA is very useful in reducing the water absorption of concrete. Also, CBA caused a slight reduction in concrete water absorption while superplasticizer caused an increase in water absorption as depicted in Fig. 5. This implies addition of 1% CBA is the optimum for reduction of concrete water absorption. Further increase in CBA has negligible effect on water absorption reduction. Likewise, a recent study reported that CBA has negligible effect on water permeability of high-performance concrete [37] which is closely related to water absorption. Also, these results also imply SP should be conservatively utilized especially where it is added to improve concrete workability. Based on the results obtained, it is advisable that SDAis combined with calcined clay to reduce the water absorption of concrete. Therefore, SDA acts as an alkali activator to counteract the negative effects of high-water absorption of calcined clay resulting in a more dense and water-resistant concrete [38]. Similar study also reported reduction in water absorption with SDA cement substitution [39]. A recent study recommended that addition of SDA up to 6% minimizes porosity resulting in more dense and compact structure [40] and it is close to the 5% obtained in this study. The water absorption results obtained in this study is less than 10 % acceptable in most construction materials [41] and < 6% limiting value of Indian Standard [42]. Increase in SDA content beyond the optimum increases the affinity SDA-concrete for water which is detrimental to the overall mechanical properties of concrete.

3.3. Compressive strength

As displayed in Fig. 6, calcined clay and sawdust ash exhibited opposing effects on compressive strength (CS). While CS decreased with increasing CC content, addition of SDA caused a slight reduction first before exhibiting an increase in CS. Similarly, CBA and SP displayed opposing effect on CS as depicted in Fig. 7. Addition of CBA caused a drop in CS before a slight increase whereas SP addition caused an increase in CS at 1% addition and a decrease at 2%. This implies addition of SP is preferable to CBA in terms of strength gain and the SP addition should not exceed 1%. Recent studies also reported increased CS with CBA [27,29]. A recent study also obtained about 50 % increase in CS between 28–90 days with 5% SDA blended-cement [43]. The CS increase at low SDA content was attributed to deceleration of hydration permitting the formation of strength contributing dicalcium silicate (C_2S) [44]. The SDA utilized in this study is within the maximum 10 % SDA limits recommended in literature to obtain beneficial concrete properties [45,46]. Also, in

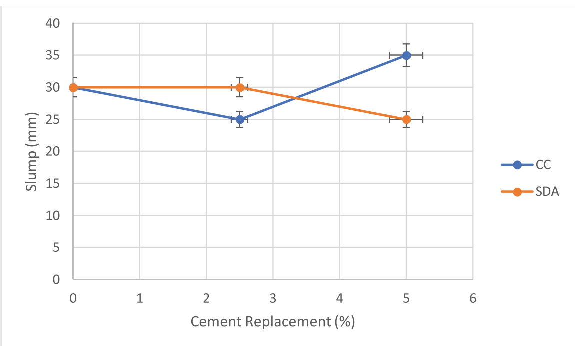

Fig. 2. Effect of calcined clay and sawdust ash on workability.

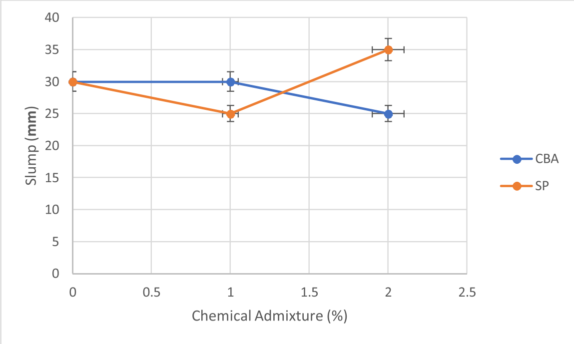

Fig. 3. Effect of chemical admixtures ash on workability.

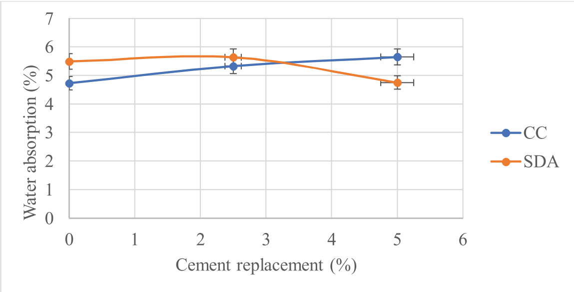

Fig. 4. Effect of calcined clay and sawdust ash on concrete water absorption.

Table 5
Experimental Results.

Trial mix	% Calcined clay	% SDA	% CBA	% SP	% Water Absorption	%Abrasion value	Compressive strength (N/mm^2)	Split tensile strength (N/mm^2)	Skid resistance (BPN)
1	5	5	1	0	4.60	14.36	9.47	0.74	76.33
2	5	2.5	0	2	7.21	9.28	11.52	1.44	69.67
3	5	0	2	1	5.65	6.98	15.65	1.99	95.33
4	0	2.5	1	1	4.62	8.12	15.61	1.69	90.67
5	2.5	0	1	2	5.90	11.36	15.02	1.75	72
6	2.5	5	0	1	4.99	8.05	18.41	1.97	67.67
7	2.5	2.5	2	0	5.10	10.15	11.89	1.94	62.67
8	0	5	2	2	4.65	9.58	15.21	1.73	68
9	0	0	0	0	4.93	7.60	14.67	1.80	67.67

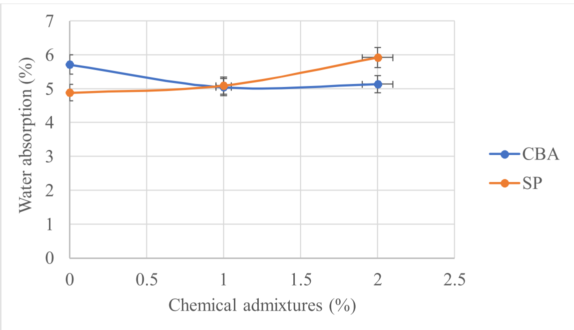

Fig. 5. Effect of chemical admixtures on concrete water absorption.

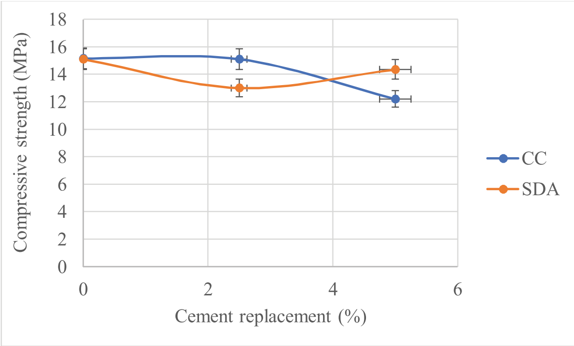

Fig. 6. Effect of calcined clay and SDA on compressive strength.

corroboration, another recent study mentioned that optimal cement replacement with agricultural residue ranges between 5–15 % [47]. Although, the highest compressive strength of 18.41 MPa obtained in this study was found to be lower than the minimum 25 MPa of a typical 28-day strength used for rigid pavement design according to Cement and Concrete Association of Australia and American Concrete Pavement Association specifications, however, for flooring application, the CS is tolerable.

3.4. Abrasion value

Abrasion value of concrete was observed to increase slightly with increasing cement replacement with CC and SDA as portrayed in Fig. 8. While SDA tends to increase concrete abrasion value further, CC tends toward stable abrasion value with increasing CC utilization. However, utilization of CBA and SP demonstrated opposing effects as shown in Fig. 9. The highest abrasion value for CBA addition was recorded at 1% addition while in contrast, the lowest abrasion value for SP was recorded at 1% addition. Also, SP tends to increase abrasion value with further increased in SP addition. A study observed highest abrasion resistance at 10 % SDA content and recommended the usage of SDA for concrete in interlocking paving units for walkways and driveways [48]. A recent study also reported optimum abrasion resistance at 10 % sawdust content in green interlocking paving units [49].

3.5. Skid resistance

Fig. 10 revealed that concrete skid resistance decreased linearly with increasing SDA addition. In contrast, the concrete skid resistance reduced up to 2.5 % cement replacement and increased significantly at 5% cement replacement with CC. On the other hand, skid resistance increased with increasing chemical admixtures up to 1% but decreased afterwards. The increment in skid resistance with SP was slightly higher than CBA at 1% chemical admixture content but also decreased afterwards as revealed in Fig. 11. Also, the measured skid resistance values obtained indicate that all the values achieved were higher than the minimum 45 of BS EN 1338: 2003 requirements. Therefore, the concretesatisfied the skid resistance requirements and is therefore fit for use in the construction of pavements.

3.6. Split tensile strength

Fig. 12 revealed that split tensile strength (STS) increased with CC addition up to 2.5 % and decreased afterwards. In contrast, STS decreased linearly with increased SDA addition. Surprisingly, STS increased with increased CBA addition while STS increased with SP addition up to 1% and decreased afterwards with further SP addition as portrayed in Fig. 13. Recent study also reported improvement

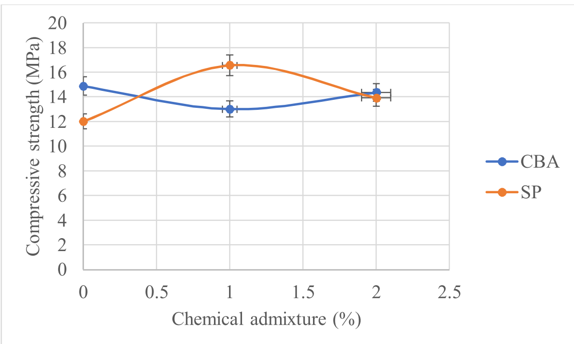

Fig. 7. Effect of chemical admixtures on compressive strength.

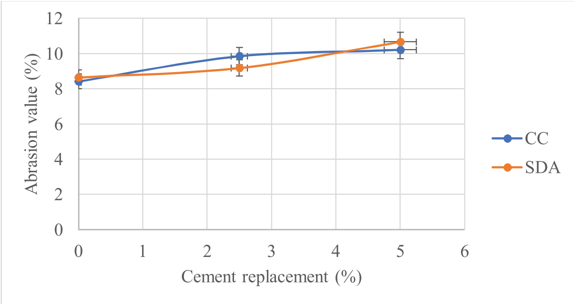

Fig. 8. Effect of calcined clay and sawdust ash on abrasion value of concrete.

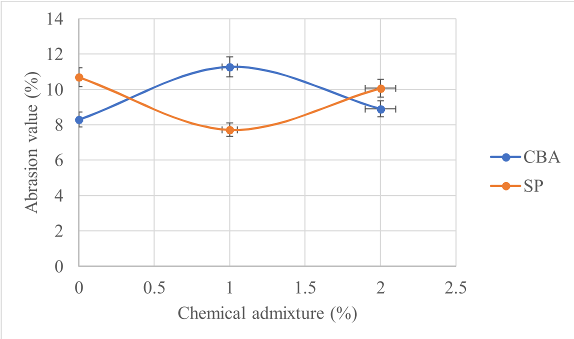

Fig. 9. Effect of chemical admixtures on concrete abrasion value.

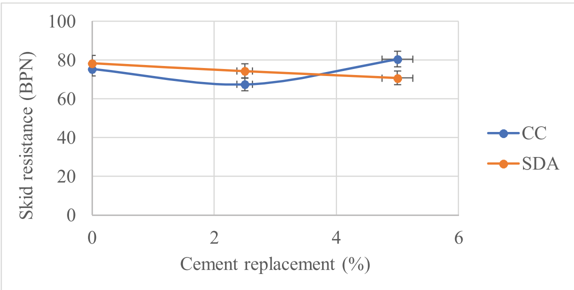

Fig. 10. Effect of calcined clay and sawdust ash on skid resistance.

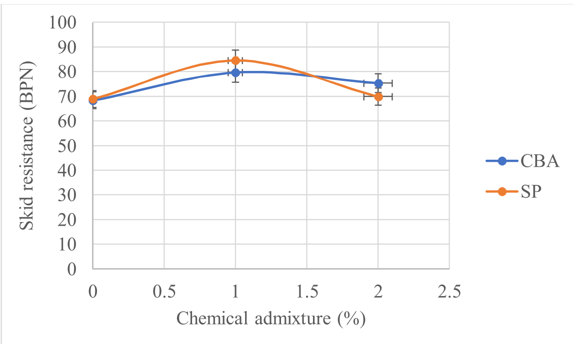

Fig. 11. Effect of chemical admixtures on skid resistance.

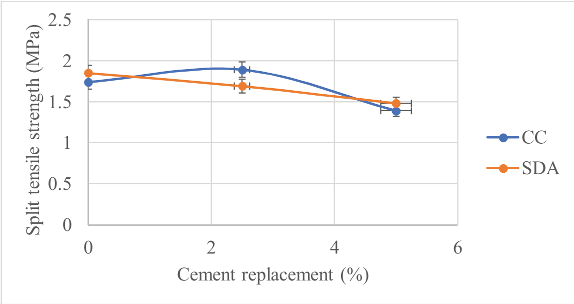

Fig. 12. Effect of calcined clay and sawdust ash on split tensile strength.

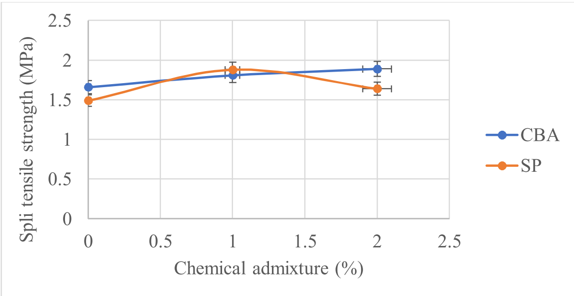

Fig. 13. Effect of chemical admixtures on split tensile strength.

in split tensile strength with CBA in full water immersion environment [29]. The improvement by CBA is attributed to self-healing properties both during and after hydration due to formation of hydration products which healed the pores and pre-cracks in concrete [29]. These results imply CC when utilized as cement replacement and SP when utilized as concrete admixture should not exceed 2.5 % and 1% respectively to avoid STS loss. Therefore, care/caution should be taken with regards to the type and dosage of chemical admixture utilized in pavement concrete mixtures. Another study obtained optimum STS at 10 % cement replacement with combination of sawdust ash and egg shell powder [50]. This implies SDA will perform better as blended cement.

3.7. Flexural strength

The flexural strength result is depicted in Figs. 14 and 15. It can be seen from Fig. 14 that there is an increase in flexural strength with increase in CC addition. In contrast, flexural Strength slightly decreased with increased SDA addition up to 2.5 % and increased afterwards. Surprisingly, for SP addition, there was an increased in the flexural strength. However, for CBA addition, there was an increase in flexural strength up to 1% and decreased afterwards with further CBA addition as portrayed in Fig. 15. In a study conducted by [50], an improvement in flexural strength with increase in the combination of sawdust ash and egg shell was observed. In another study conducted by [51], the results showed an increased in flexural strengths by using an optimum blend of superplasticizer type, dosage and liquid/solids ratio. An optimum superplasticizer dosage of 2% was achieved from the study. This study has also observed a similar trend. Also, the 28-day flexural strengths obtained for test numbers were found to exceed minimum 3.5Mpa for a typical 28-day

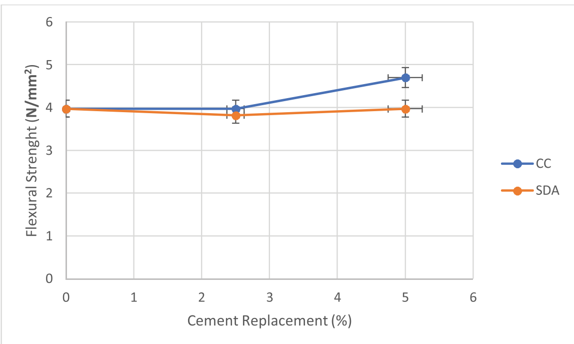

Fig. 14. Effect of calcined clay and sawdust ash on flexural strength.

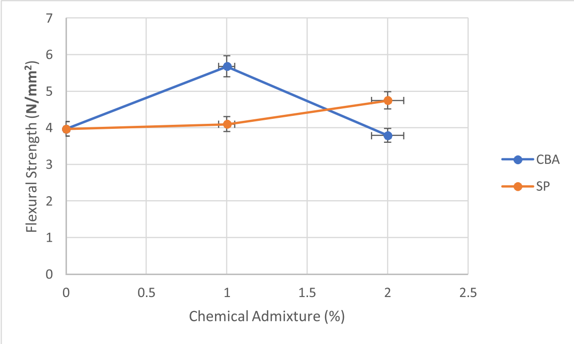

Fig. 15. Effect of chemical admixtures on flexural strength.

flexural strength value for rigid pavement design according to cement and Concrete Association of Australia and American Concrete Pavement Association.

3.8. Optimum values

The optimum cement substitution with CC and SDA for maximum abrasion value alone is 5%. In addition, the optimum percentage of CBA is 1% to obtain high abrasion value alone while SP is not advisable to be utilized due to significant reduction in abrasion value. With respect to skid resistance, the optimum value of calcined clay is 5% while SDA is not recommended to be utilized due to significant linear reduction with increased SDA addition. Furthermore, the optimum cement substitution for flexural strength is 5% CC with 1% CBA. In corroboration, earlier research has recommended that utilization of SDA-modified concrete should be limited to non-structural applications [52]. Also, a recent study obtained the best self-healing property of crystalline-based admixtures at 10 % cement replacement with ground granulated blast furnace slag [53]. However, considering flexural strength, abrasion and skid resistance simultaneously, the optimum CC content of 5% and 1% CBA is recommended. Alternatively, sawdust ash may be utilized as additive to reduce water absorption of calcined clay concrete without jeopardizing the mechanical, abrasion and skid resistance of the concrete pavement. Optimum CC of 5% as partial cement replacement improves flexural strength, improves abrasion resistance and lowers water absorption.

4. Conclusions

This study evaluated the effects of cement substitution with calcined clay and SDA on the skid resistance, abrasion resistance, mechanical strength of rigid pavement concrete. The main conclusions from the study are as follows:

1 Calcined clay partial cement substitution is preferable to sawdust ash cement substitution as it gives higher skid resistance and comparatively similar abrasion value.
2 Sawdust ash can be utilized as partial cement substitution in non-pavement concrete applications such as flooring and bricks owing to its lower water absorption and slightly higher compressive strength.
3 Comparatively, crystalline-based admixture (CBA) seems preferable when high quantities of chemical admixture is required to improve the properties (mechanical strength, skid and abrasion resistance) of pavement concrete.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work presented in this paper.

Acknowledgments

The authors are gratefully acknowledged Advanced Concrete Technology Limited, Ikeja, Lagos State for providing the crystalline based admixture and superplasticizer used in the study. Also, authors appreciate Ire clay production company for providing the clay used the study.

References

[1] M. Rith, Y.K. Kim, S.W. Lee, Characterization of long-term skid resistance in exposed aggregate concrete pavement, Constr. Build. Mater. 256 (2020) 1–8.
[2] X. Zhu, Y. Yang, H. Zhao, D. Jelagin, F. Chen, F.A. Gilabert, A. Guarin, Effects of surface texture deterioration and wet surface conditions on asphalt runway skid resistance, Tribol. Int. 153 (2021) 1–16.
[3] E.J. Elizondo-Martinez, V.C. Andres-Valeri, D. Jato-Espino, J. Rodriguez-Hernandez, Review of porous concrete as multifunctional and sustainable pavement, J. Build. Eng. 17 (2020) 1–9.
[4] Z. Zhang, B. Luan, X. Liu, M. Zhang, Effects of surface texture on tire-pavement noise and skid resistance in long freeway tunnels: from field investigation to technical practice, Appl. Acoust. 160 (2020) 1–11.
[5] O. Xu, S. Han, Y. Liu, C. Li, Experimental investigation surface abrasion resistance and surface frost resistance of concrete pavement incorporating fly ash and slag, Int. J. Pavement Eng. (2020) 1–9.
[6] W. Ren, S. Han, J. Li, M. Liu, Investigation of the relative abrasion resistance of concrete pavement with chip-sprinkled surfaces, Wear 382–383 (2017) 95–101.
[7] S. Yazici, G. Inan, An investigation on the wear resistance of high strength concretes, Wear 260 (2006) 615–618.
[8] E. Hoszczaruk, Abrasion resistance of high-strength concrete in hydraulic structures, Wear 259 (2005) 62–69.
[9] H. Li, M.H. Zhang, J.P. Ou, Abrasion resistance of concrete containing nano-particles for pavement, Wear 260 (2006) 1262–1266.
[10] I. Pranjic, A. Deluka-Tibljac, M. Cuculic, S. Surdonja, Influence of pavement surface macrotexture on pavement skid resistance, Transp. Res. Proced. 45 (2020) 747–754.
[11] R.B. Kogbara, E.A. Masad, E. Kassem, A.T. Scarpas, K. Anupam, A state-of-the-art review of parameters influencing measurement and modelling of skid resistance of asphalt pavements, Constr. Build. Mater. 114 (2016) 602–617.
[12] H. Perez-Acebo, H. Gonzalo-Orden, D.J. Findley, E. Roji, A skid resistance prediction model for an entire road network, Constr. Build. Mater. 262 (2020) 1–18.
[13] V. Nicolosi, M. D'Apuzzo, A. Evangelisti, Cumulated frictional dissipated energy and pavement skid deterioration: evaluation and correlation, Constr. Build. Mater. 263 (2020) 1–10.
[14] J.W. Hall, K.L. Smith, L. Titus-Glover, J.C. Wambold, T.J. Yager, Z. Rado, Guide for pavement friction, in: T.R. Board (Ed.), Transportation Research Board, U.S. A., 2009.
[15] P. Ghoddousi, M. Zareechian, A.A.S. Javid, A.H. Korayem, Microstructural study and surface properties of concrete pavements containing nanoparticles, Constr. Build. Mater. 262 (2020) 1–16.
[16] L. Hu, D. Yun, J. Gao, C. Tang, Monitoring and optimizing the surface roughness of high friction exposed aggregate cement concrete in exposure process, Constr. Build. Mater. 230 (2020) 1–12.
[17] B.D. Scott, M. Safiuddin, Abrasion resistance of concrete – design, construction and case study, Concr. Res. Lett. 6 (2015) 136–148.
[18] C.N.A. Sleiman, X. Shi, D.G. Zollinger, Approach to characterize the wearability of concrete pavement surface treatments, Transp. Res. Rec. 2673 (2019).
[19] A.A. Bawono, B. Lechner, E.H. Yang, Skid resistance and surface water drainage performance of engineered cementitious composites for pavement applications, Cem. Concr. Compos. 104 (2019) 1–8.
[20] K.M.H. Jalal, A. Hassani, J. Sodagari, Introduction and application of rotational abrasion device to determine concrete pavement abrasion, Civ. Eng. Infrast. 52 (2019) 295–308.
[21] T. Tang, K. Anupam, C. Kasbergen, A. Scarpas, S. Erkens, A finite element study of rain intensity on skid resistance for permeable asphalt concrete mixes, Constr. Build. Mater. 220 (2019) 464–475.
[22] M. Adamu, B.S. Mohammed, N. Shafiq, M.S. Liew, Skid Resistance of nano silica modified roller compacted rubbercrete for pavement applications: experimental methods and response surface methodology, Cogent Eng. 5 (2018) 1–13.
[23] M.D.W. Ardana, I.M.A. Ariawan, The significance of concrete slab flexural strength inference variation based on its compression strength characteristics in apron pavement analysis and design, in: MATEC Web of Conferences, Vol. 276, 2019, p. 01038, https://doi.org/10.1051/matecconf/201927601038. EDP Sciences.
[24] A.K. Chandrappa, K.P. Biligiri, Investigation on flexural strength and stiffness of pervious concrete for pavement applications, Adv. Civ. Eng. Mater. 7 (2) (2018) 223–242, https://doi.org/10.1520/ACEM20170015. ISSN 2379-1357.
[25] F. Hassouna, Y.W. Jung, Developing a higher performance and less thickness concrete pavement: using a nonconventional concrete mixture, Adv. Civ. Eng. 2020 (2020), https://doi.org/10.1155/2020/8822994.
[26] K. Tamanna, S.N. Raman, M. Jamil, R. Hamid, Utilization of wood waste ash in construction technology: a review, Constr. Build. Mater. 237 (2020) 1–11.
[27] M. Nasim, U.K. Dewangan, S.V. Deo, Autonomous healing in concrete by crystalline admixture: a review, Mater. Today Proceed. 32 (2020) 638–644.
[28] C.M.K. Reddy, B. Ramesh, D. Macrin, Effect of crystalline admixtures, polymers and fifibers on self healing concrete - a review, Mater. Today Proceed. (2020).
[29] T.C.S. Reddy, A. Ravitheja, Macro mechanical properties of self healing concrete with crystalline admixture under different environments, Ain Shams Eng. J. 10 (2019) 23–32.
[30] M. Roig-Flores, F. Pirritano, P. Serna, L. Ferrara, Effect of crystalline admixtures on the self-healing capability of early-age concrete studied by means of permeability and crack closing tests, Constr. Build. Mater. 114 (2016) 447–457.
[31] E. Cuenca, A. Tejedor, L. Ferrara, A methodology to assess crack-sealing effectiveness of crystalline admixtures under repeated cracking-healing cycles, Constr. Build. Mater. 179 (2018) 619–632.
[32] A.A. Raheem, B.S. Olasunkanmi, C.S. Folorunso, Saw dust ash as partial replacement for cement in concrete, Organ. Technol. Manag. Constr. Int. J. 4 (2) (2012) 474–480.
[33] M.J. Al-Kheetan, M.M. Rahman, D.A. Chamberlain, A novel approach of introducing crystalline protection material and curing agent in fresh concrete for enhancing hydrophobicity, Constr. Build. Mater. 160 (2018) 644–652.
[34] T.F. Awolusi, L.O. Oke, O.O. Akinkurolere, D.P. Ubani, R.T. Bamisaye, O.G. Aluko, The application of response surface methodology in understanding the compressive strength and water absorption capacity of sandcrete blocks, Silicon (2020) 1–10.
[35] C.C. Ikeagwuani, Compressibility characteristics of black cotton soil admixed with sawdust ash and lime, Nig. J. Tech. 35 (2016) 718–725.
[36] A.-. C618, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolans for Use in Concrete, ASTM International, Washington D.C, USA, 2019.
[37] P. Escoffres, C. Desmettre, J.P. Charron, Effect of a crystalline admixture on the self-healing capability of high-performance fifiber reinforced concretes in service conditions, Constr. Build. Mater. 173 (2018) 763–774.
[38] B.C. De Santis, J.A. Rossignolo, M.R. Morelli, Calcined clay lightweight ceramics made with wood sawdust and sodium silicate, Materials 19 (2016) 1437–1442.
[39] A.U. Ellinwa, S.P. Ejeh, Effects of incorporation of saw dust incineration fly ash in cement pastes and mortars, J. Asian Arch. Build. Eng. 3 (2004) 1–7.
[40] T.E. Elahi, A.R. Shahriar, M.K. Alam, M.Z. Abedin, Effectiveness of saw dust ash and cement for fabrication of compressed stabilized earth blocks, Constr. Build. Mater. 259 (2020) 1–11.
[41] S. Chowdhury, M. Mishra, O. Suganya, The incorporation of wood waste ash as a partial cement replacement material for making structural grade concrete: an overview, Ain Shams Eng. J. 6 (2015) 429–437.
[42] IS-15658, Precast Concrete Blocks for Paving – Specification, Bureau of Indian Standards, India, 2006.
[43] A.A. Raheem, A.I. Ige, Chemical composition and physicomechanical characteristics of sawdust ash blended cement, J. Build. Eng. 21 (2019) 404–408.
[44] S. Bhanja, B.B. Senguptab, Investigation on the compressive strength of silica fume concrete using statistical methods, Cem. Concr. Res. 32 (2002) 1391–1394.
[45] A.U. Elinwa, Effect of addition of sawdust ash to clay bricks, Civ. Eng. Environ. Syst. 23 (2006) 263–270.
[46] C. Marthong, Sawdust ash (SDA) as partial replacement of cement, Int. J. Eng. Res. Appl. 2 (2012) 1980–1985.

[47] A.A. Raheem, B.D. Ikotun, Incorporation of agricultural residues as partial substitution for cement in concrete and mortar – a review, J. Build. Eng. 31 (2020) 1–10.
[48] R.A. Ayinde, A.S. Idowu, A.B. Raphael, A.O. Adedapo, A.B. Olayemi, Application of saw dust ash as partial replacement for cement in the production of interlocking paving stones, Int. j. Sust. Constr. Eng. 8 (2017) 1–11.
[49] A.O. Sojobi, O.J. Aladegboye, T.F. Awolusi, Green interlocking paving units, Constr. Build. Mater. 173 (2018) 600–614.
[50] A.A. Ogbonna, M. Abubakar, Characterization of ternary batched concrete parking lots on the ground containing sawdusts ash and egg shell powder, J. Sustain. Archit. and Civ. Eng. 4 (2017) 82–89.
[51] M. Shirkavand, R. Baggott, Effects of superplasticizer on workability and flexural strength of autoclaved calcium silicates, Cem. Concr. Res. 25 (7) (1995) 1512–1522.
[52] T.F. Awolusi, A.O. Sojobi, J.O. Afolayan, SDA and laterite applications in concrete: prospects and effects of elevated temperature, Cogent Eng. 4 (2017) 1–20.
[53] G. Li, S. Liu, M. Niu, Q. Liu, X. Yang, M. Deng, Effect of granulated blast furnace slag on the self-healing capability of mortar incorporating crystalline admixture, Constr. Build. Mater. 239 (2020) 1–11.