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Investigation of the effect of alkali silica reaction (ASR) on properties of concrete pavement admixed with cow bone ash (CBA) by electrical resistivity test

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Abstract. The use of concrete in road pavements construction in view of its durability and cost effectiveness over time have gained momentum. Cement concrete pavements however suffer deterioration due to Alkali-Silica Reaction (ASR). This study therefore investigates the use of Cow Bone Ash (CBA) in mitigating the effect of ASR using electrical resistivity test (schlumberger array probe method). The results are then compared with American Society for Testing and Materials (ASTM) standards and relevant literatures. The result of the study showed that the average resistivity at 0%, 5%, 10%, 15%, 20% and 30% CBA replacement are 298.87 Ωm, 306.23 Ωm, 215.02 Ωm, 489.31 Ωm, 382.34 Ωm and 272.53 Ωm respectively. This indicates that the peak resistivity is obtained at 15% CBA replacement which is the optimal replacement level for ASR inhibition in the concrete. The result also shows that the concrete samples are corrosion free with the least resistivity value on the 7^{th} day at 30% CBA addition (163.03 Ωm) and the maximum value at 20% CBA addition on the 56^{th} Day (1069.54 Ωm). The study concluded that ASR and reinforcement corrosion can be effectively controlled between 15% and 20% cement replacement by CBA in concrete/rigid pavements.

1. Introduction

Nigerian roads suffer from faulty geometric and pavement designs, inadequate construction, unregulated axle loading, inadequate drainage system and poor maintenance culture, which have significantly reduced the utility of the roads. There are potholes, degradation of pavements, fallen bridges, etc., along most Nigerian roads. These roads have been exposed to excessive pressure because of expanded vehicular traffic given the close nonattendance of rail, marine and other forms of transport to convey passengers and heavy goods. Several remedies have been proposed to solve the road transportation problems of Nigeria and one of such remedies is the construction of rigid pavements. Rigid pavements have several advantages which include ability to withstand higher traffic roads, longer design life, safety and economic benefits amongst other benefits that accrue to it as against the flexible pavements on majority of Nigerian roads. The flexible pavements have not been able to serve their intended design life before they become deteriorated and need either reconstruction or periodic maintenance. However, concrete which is the main constituent in the rigid pavement layer suffers a major setback due to Alkali-Silica Reaction which tends to negatively affect the structural and physical characteristics of the rigid pavement. Alkali-Silica Reaction (ASR) is a serious problem in concrete as related to rigid pavement considering that once it occurs, no repair methods are available to efficiently and definitely stop the process of ASR and associated damage hence the best approach is to mitigate it from the onset.

In the last few decades, strength of concrete and pavement structures have been of major concerns. This has necessitated studies on use of replacement materials in concrete mixtures [1, 2, 3, 4, 5, 6]. The durability of pavement concrete slabs has direct implications on the life span of engineering structures. Self-consolidating concrete (SCC) have been identified to have high performance without application of mechanical consolidating effort [7, 8, 9]. However, SCC requires fillers to be of advantage over vibrated concrete [6]. One major benefit of supplementary cementitious materials (SCMs) often used as powdered filler is the ability to reduce pore spaces [1, 10, 11]; leading to increased resistivity and by extension, strength. Previously studied SCMs among others, in relation to electrical resistivity include rice husk ash- RHA [3]; fly ash- FA [5, 6]. High content of rice husk ash- RHA over a range of percentage replacement for cement showed high electrical resistivity [3], while fly ash- FA resulted in significant increase in resistivity of concrete material, though micro limestone powders often serves as additive to arrest the delays in setting time found to be associated with fly ash [6, 12, 13]

Recently reported use of cow bone ash (CBA) as supplementary cementitious materials [14] is most likely connected to the need for economical utilization of the huge available cow bone wastes generated from the local abattoirs. Durability performance of CBA under aggressive condition has been analyzed to be more effective at 10% replacement ratio [14]; however, this study investigated the electrical resistivity testing on CBA, as indices of strength, effect on corrosion and its alkali-silica reaction ability in concrete slabs at varying percentage replacements; ranging from 0% to 30% over a 56 days' experimental plan.

2. Materials and Method Used

Cow bones used in this study were collected as refuse from abattoirs in Akure, Ondo State, Nigeria where cows are being slaughtered for consumption. The cow bones were sun dried in open air and burnt to ash in an electric furnace (Carbolite GPC 12/65) at 750°C for 90 minutes. The clinker was grinded to fine powder and passed through the 150µm sieve. The sharp sand and granite used were obtained from Akure, Ondo State. Nigeria. The cement used was Dangote 3X 42.5R from Dangote Portland Cement Company distributors in Ondo State.

The testing program conducted on the materials (cement, sand, coarse aggregate and cow bone ash) includes determination of their physical and chemical properties in their natural state by carrying out sieve analysis test, chemical analysis and specific gravity. The proportioning of the concrete components including water was done according to Road Note 4 methodology. The concrete is then modified with partial substitution of cement with 0%-30% variation of the selected pozzolan (Cow Bone Ash) and electrical resistivity test (7^{th}, 14^{th}, 21^{st}, 28^{th} and 56^{th} day).

2.1 Electrical resistivity test using Schlumberger array probe method

Electrical resistivity is a material property that can be utilized for different purposes, one of which is to recognize early age properties of fresh concrete. When the fresh concrete sets and hardens, depercolation (discontinuity) of the capillary pore space leads to an increase in its electrical resistivity. The Schlumberger array was adopted in this study. The array has a number of advantages, among these are that fewer movement of the electrodes are needed, lower level of error due to lateral variations in resistivity. The duplication of readings with the same values of half-current electrode spacing (AB/2) but different values of potential electrode spacing (MN/2) allows for an approximate correction to be made for the effects of lateral variation. Furthermore, it is less sensitive to near surface lateral inhomogeneity's because the potential electrodes (M and N) remain in fixed position during a large number of successive measurements. Figure 1 shows the electrical resistivity nodes arrangement while Figure 2 and 3 shows the experimental setup for record taking.

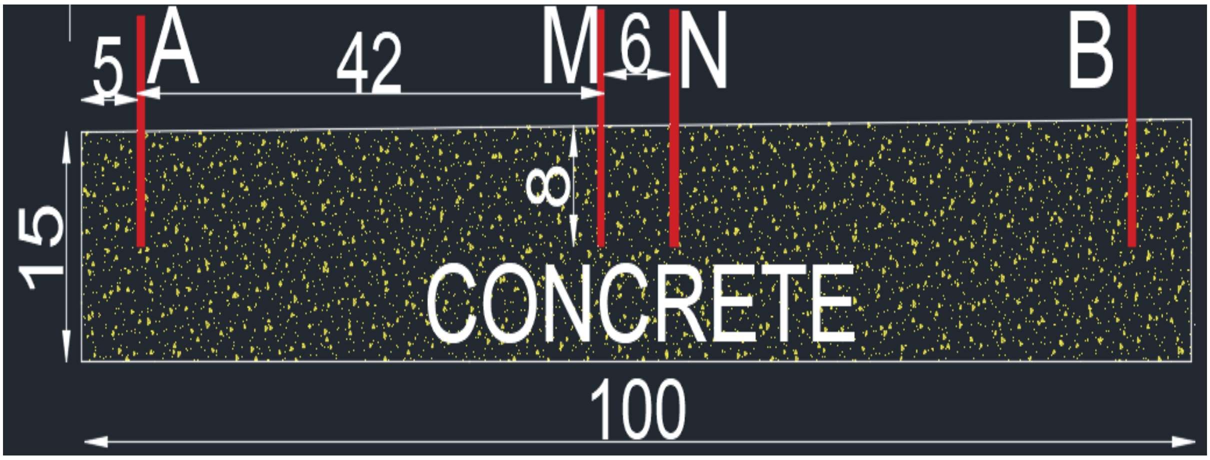


Figure 1: Setup showing positioning of electrodes in the concrete

Figure 2: Concrete cast with electrodes inserted for electrical resistivity test

Figure 3: Experimental setup for electrical resistivity showing the anode and cathode

Resistivity (ρ) is calculated from: ρ = GR

Where: G = dimensionless geometry correction factor
AB = distance between the electrodes (90 cm)
MN = distance between inner electrodes = 6 cm

$$G = \frac{\left(\frac{AB}{2}\right)^2}{MN} \quad (1)$$

$$\rho = \frac{\left(\frac{AB}{2}\right)^2}{MN} \pi R \quad (2)$$

therefore, $\frac{AB}{2} = \left(\frac{90}{2}\right) = 45$ cm = 0.45 m

MN = 6 cm = 0.06 m (From Figure 1)

$$G = \frac{\left(\frac{0.45}{2}\right)^2}{0.06} \pi = \frac{0.2025\ m}{0.06\ m} * 3.142 = 10.6$$

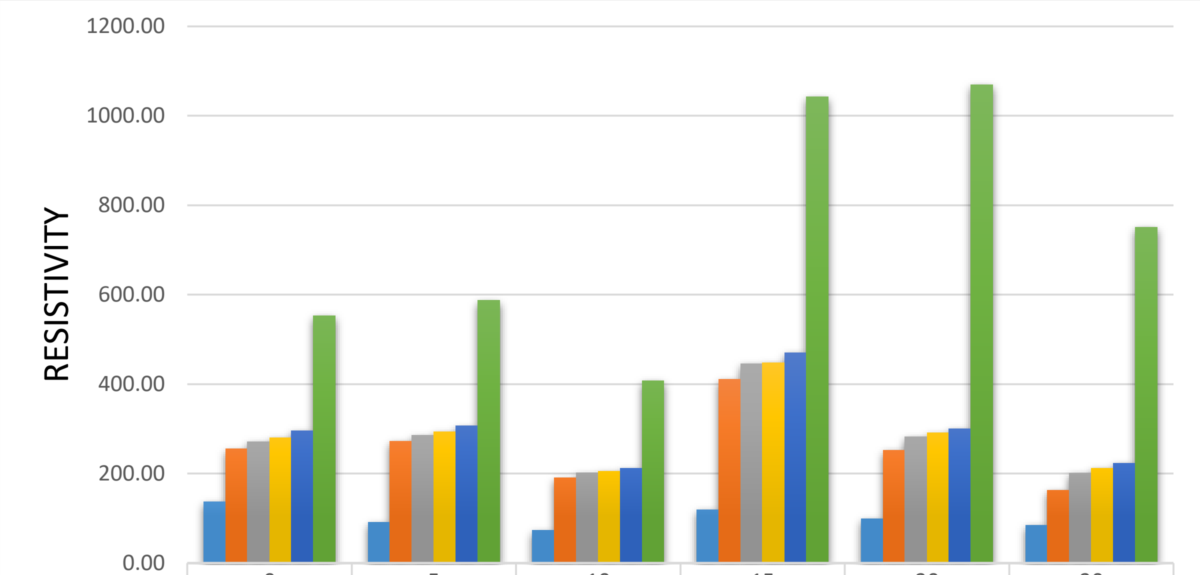
3. Results and Discussion

Electrical Resistivity test using Schlumberger array probe method is very effective in determining the strength and effects of ASR on both fresh and hardened concrete as revealed in the findings of this study. The resistance and resistivity is as measured in the concrete samples for a duration of 56 days and it is presented in Table 1 and Figure 4.

The study revealed that at day 1, the resistivity of the concrete cubes reduced from 137.38 Ωm at 0% CBA addition to 85.01 Ωm at 30% CBA addition. The study revealed that at day 7 the resistivity of the concrete cubes at 0% CBA is 255.354 Ωm and reduced to163.03 Ωm at 30%. The same trend of resistivity reduction was also observed at day 14 and 28 but on day 56, the study revealed an increase in resistivity at 0% CBA addition (552.68 Ωm) compared to 30% CBA addition (751.22 Ωm). Resistivity of the concrete cube samples for the same percentage of CBA addition however are shown to be increasing at the varying days with the least values obtainable on day 1 (137.38 Ωm, 91.48 Ωm, 73.03 Ωm, 119.04 Ωm, 99.22 Ωm, 85.01 Ωm) on the 1st, 7th, 14th, 21st, 28th and 56th days respectively. The maximum values were also obtained on the 56th day (552.68 Ωm, 587.02 Ωm, 407.78 Ωm, 1042.09 Ωm, 1069.54 Ωm, 751.22 Ωm) as revealed on the 1st, 7th, 14th, 21st, 28th and 56th days respectively.

Table 1: Resistance and Resistivity Values obtained from the Concrete Cubes

Percentage Replacement	0% CBA	5% CBA	10% CBA	15% CBA	20% CBA	30% CBA
Day 1						
Resistance (Ω)	12.96	8.63	6.89	11.23	9.36	8.02
Resistivity	137.38	91.48	73.03	119.04	99.22	85.01
Day 7						
Resistance (Ω)	24.09	25.71	18.02	38.73	23.79	15.38
Resistivity	255.35	272.53	191.01	410.54	252.17	163.03
Day 14						
Resistance (Ω)	25.62	26.93	19.03	42.06	26.62	18.93
Resistivity	271.57	285.46	201.72	445.84	282.17	200.66
Day 21						
Resistance (Ω)	26.42	27.74	19.36	42.26	27.43	20.04
Resistivity	280.05	294.04	205.22	447.96	290.76	212.42
Day 28						
Resistance (Ω)	27.94	28.95	19.94	44.38	28.32	21.02
Resistivity	296.16	306.87	211.36	470.43	300.19	222.81
Day 56						
Resistance (Ω)	52.14	55.38	38.47	98.31	100.90	70.87
Resistivity	552.68	587.03	407.78	1042.09	1069.54	751.22



	0	5	10	15	20	30
DAY 1	137.38	91.48	73.03	119.04	99.22	85.01
DAY 7	255.35	272.53	191.01	410.54	252.17	163.03
DAY 14	271.57	285.46	201.72	445.84	282.17	200.66
DAY 21	280.05	294.04	205.22	447.96	290.76	212.42
DAY 28	296.16	306.87	211.36	470.43	300.19	222.81

Figure 4: Graph of Resistivity of Concrete Cubes

The findings of the study are shown in Table 2 which reveals the average resistance and resistivity values obtained from the concrete cubes with Figure 5 showing the graph of average resistance of concrete cubes. Figure 6 shows the graph of average resistivity of concrete cubes for CBA addition while Figure 7 shows the graph of average resistivity of concrete cubes for varying days.

Table 2: Average Resistance and Resistivity Values obtained from the Concrete Cubes

Percentage Replacement	0% CBA	5% CBA	10% CBA	15% CBA	20% CBA	30% CBA
Resistance	28.20	28.89	20.29	46.16	36.07	25.71
Resistivity	298.87	306.23	215.02	489.31	382.34	272.53

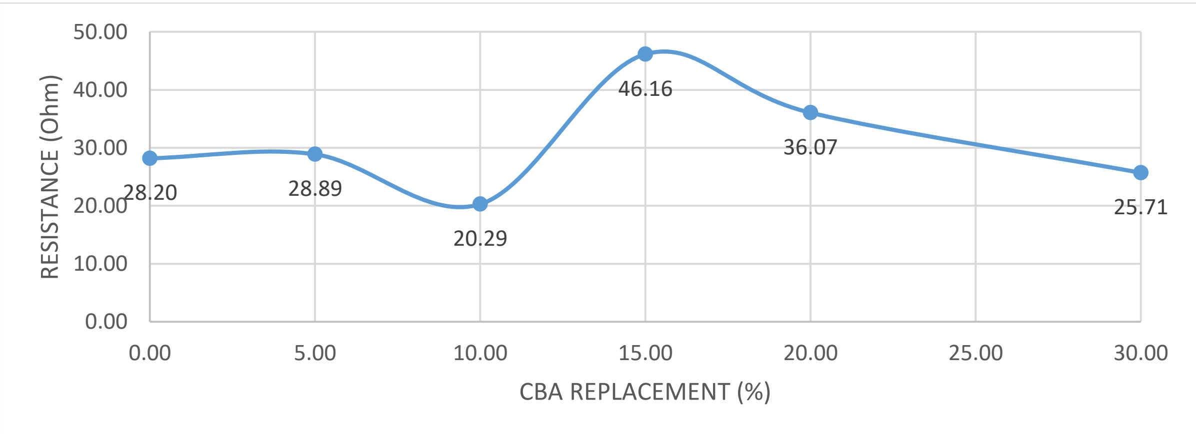


Figure 5: Graph of Average Resistance of Concrete Cubes

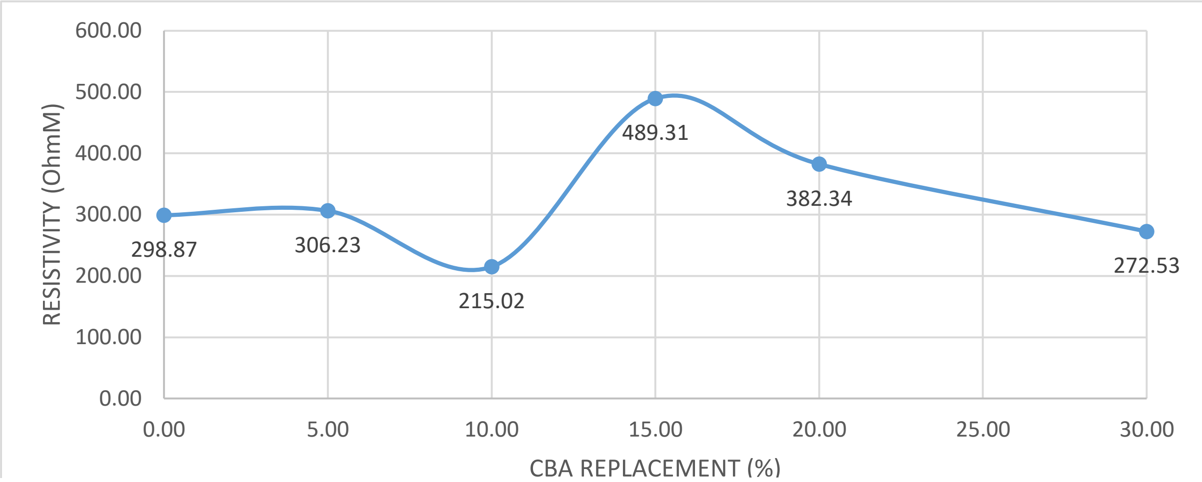


Figure 6: Graph of Average Resistivity of Concrete Cubes for CBA Addition

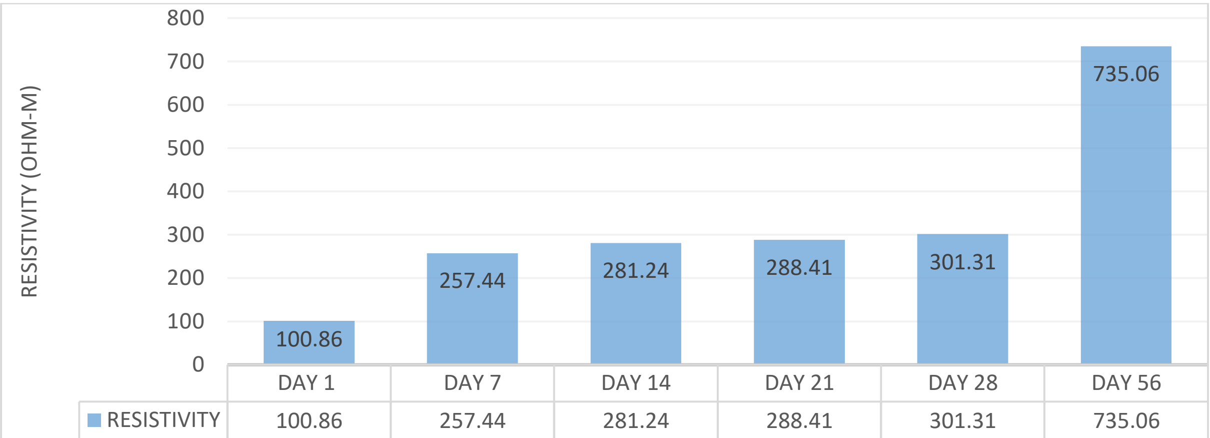


Figure 7: Graph of Average Resistivity of Concrete Cubes for Varying Days

The average resistance of the concrete cube samples on addition of the CBA shows that at 0% CBA replacement, the resistance is 28.20 Ω, at 5% CBA replacement the resistance increased to 28.89 Ω, there was a drop in resistance (20.29 Ω) at 10% CBA replacement. There was an increase in resistance at 15% CBA replacement giving a resistance value of 46.16 Ω, at 20% CBA replacement, resistance is 30.07 Ω and at 30% CBA replacement, the resistance value obtained in the study is 25.71 Ω. The average resistivity of the concrete cube samples on addition of the CBA shows that at 0% CBA replacement, the resistivity is 298.87 Ωm, at 5% CBA replacement the resistivity increased to 306.23 Ωm, there was a drop in resistivity (215.02 Ωm) at 10% CBA replacement. There was an increase in resistivity at 15% CBA replacement giving a resistivity value of 489.31 Ω, at 20% CBA replacement, resistivity is 382.34 Ωm and at 30% CBA replacement, the resistivity value obtained in the study is 272.53 Ωm. The average resistivity for the varying days are as presented in Figure 4. The study revealed that the resistivity of the concrete samples increases with increasing number of days. The average resistivity for all the samples (0% - 30% CBA replacement) on the 1st day is observed to be 100 Ωm. The average resistivity increased to 257.44 Ωm on the 7th day, 281.24 Ωm on the 14th day, 288.41 Ωm on the 21st day, 301.31 Ωm on the 28th day and 735.06 Ωm on the 56th day.

The resistance and resistivity values of the concrete cubes both had peak values at 15% CBA replacement with values of 46.16 Ω and 489.31 Ωm respectively. These values show a 38.93% increase in resistance and resistivity compared to 0% CBA addition, 37.41% increase in resistance and resistivity compared to 5% CBA addition, 56.04% increase in resistance and resistivity compared to 10% CBA

addition, 21.86% increase in resistance and resistivity compared to 20% CBA addition and 44.30% increase in resistance and resistivity compared to 30% CBA addition.
These results could be due of flocculation that occurs in the concrete samples as they converge at the 15% CBA replacement and subsequent diverging of the concrete samples on addition of more CBA thereby making their resistance and resistivity to decrease as divergence increases.

3.1 Resistivity, Strength and ASR reduction of Concrete Cubes

Replacement of Ordinary Portland Cement (OPC) with Silica Fume by [15] at 0%, 7.5% and 10% resulted in average resistivity values of 323.392 Ωm, 452.025 Ωm and 325.815 Ωm respectively. However, resistivity values obtained on replacing OPC with CBA at 0%, 5%, 10%, 15%, 20% and 25% in this present study include 298.87 Ωm, 306.23 Ωm, 215.02 Ωm, 489.31 Ωm, 382.34 Ωm and 272.53 Ωm respectively.

A comparison of these results, generally shows a similar trend as resistivity values tend to drop after an optimum has been reached. Specifically, [15] obtained optimum resistivity value of 452.025 Ωm at 7.5% replacement of OPC with Silica Fume ash whereas the optimum average resistivity obtained in this present study was about 489.31 Ωm obtained on replacing 15% of OPC with CBA. This shows that in comparison to Silica Fume, more quantity of CBA would be required to obtain optimum resistivity properties.

In both CBA and Silica fume replacements it was found that some resistivity values were higher while others were lower than those obtained for the control mix (without replacement). This implies a non-linear relationship between quantity of both cementitious materials and electrical resistivity values. Since, a reduction in alkali-silica reaction improves concrete structure by decreasing concrete porosity and reducing ionic transmission thereby leading to higher electrical resistivity values. It could be said that the results above imply that Silica fume possesses slightly higher capability to reduce Alkali-silica reaction in concrete than CBA as it (silica fume) displayed higher electrical resistivity property.

Several Supplementary Cementitious Materials (SCM) were used by [16] as replacement for OPC in different concrete mixes. The SCMs used include, Silica flume, Fly ash, Metakolin particles and Vitrified Calcium Alumino Silicates. The study revealed the electrical resistivity of the various mixes with the different SCMs at 20% replacement. For 7, 14, 28 and 56 days, test results gave average resistivity values of 1042.75 Ωm, 718.75 Ωm, 272.75 Ωm, 195.75 Ωm for, Silica flume, Metakolin particles, Vitrified Calcium Alumino Silicates and Fly ash respectively. However, in the present study 20% replacement of OPC with CBA yielded an average resistivity value of 382.34Ωm. A comparison of the results showed that for 20% replacement of OPC in concrete, Silica Flume and Metakolin SCMs had higher electrical resistivity properties than CBA while Vitrified Calcium Alumino Silicates and Fly ash displayed lower electrical resistivity. [16] shows that Silica fume and Metakaolin boosted higher concrete electrical resistivity because of changing the pore structure and the small size of their materials. It therefore, follows that the ability of an SCM to change the pore structure of the mix will lead to higher electrical resistivity. This implies that the CBA has higher pore structure changing capability than fly ash and Vitrified Calcium Alumino Silicates. Whereas its pore structure changing capabilities are lower than those of Silica fume and Metakolin. [16] also stated that Silica fume and Metakaolin boosted higher concrete electrical resistivity because of the small size of their materials, thereby implying that CBA particles are larger in size than those of Silica flume and Metakolin and finer in size than those of fly ash and Vitrified Calcium Alumino Silicates. From the foregoing, it could be seen that the size of the SCM material particles and ability to change pore structure is largely responsible for high resistivity values of concrete. This means that superior resistivity properties can be induced into concrete CBA as replacement for OPC, if the CBA particles could be made of finer sizes. From the foregoing comparison of various SCMs, it could be stated that at 20% replacement of OPC with CBA has better ability in reducing ASR.

3.2 Resistivity and Concrete Reinforcement Corrosion

According to [17] when resistivity (ρ) is greater or equal to 120 Ωm, corrosion is unlikely, when ρ is between 80 Ωm to 120 Ωm, corrosion is possible, but when ρ is less than 80 Ωm, corrosion is fairly certain. Relating these to the findings of this study, rigid pavements are usually reinforced and this invariably affects the disintegration/ formation of cracks in a rigid pavement due their ability to withstand tension from traffic loadings as concrete is weak in it. Rigid pavements with high resistivity thereby inhibits ASR developments that will have aided the formation of crack and subsequent failure of pavement arising from reinforcement corrosion.

Figure 1 shows that at day 1 when the concrete is in its fresh state, only the concrete sample with 0% CBA addition will be corrosion free as it has a resistivity value of 137.38 Ωm. Concrete samples of 5% CBA (91.48 Ωm), 15% CBA (119.04 Ωm), 20% CBA (99.22 Ωm), 30% CBA (85.01 Ωm) are all likely to be corrosive in nature. Concrete sample at 10% CBA addition shows that corrosion is imminent as it has a resistivity value of 73.03 Ωm. Resistivity values for all other days (7^{th}, 14^{th}, 21^{st}, 28^{th} and 56^{th}) and CBA percentage addition shows that the concrete samples are corrosion free with the least resistivity value obtained at day 7 at 30% CBA addition (163.03 Ωm) and the maximum value obtained at 20% CBA addition in Day 56 (1069.54 Ωm).

4. Conclusion

Concrete pavements stands as a good alternative to flexible pavements considering their merits on the long term. However, the pavement suffers defects that does not allow operate optimally during its service life and on the long term. Alkali silica reaction (ASR) is a determining factor that triggers defects in pavement and the effect of using cow bone ash (CBA) using electrical resistivity method which is a non-destructive concrete pavement test is being investigated in this study. The study revealed that concrete pavements admixed with 15% CBA replacement produced the best results in terms of resistance (46.16 Ω) and resistivity (489.31 Ωm). This indicates that at the 15% CBA replacement, the concrete pavement would achieve its maximum strength and the CBA would optimally fill in the concrete pore spaces there inhibiting the development of gels around the concrete which could have caused ASR that would have led pavement disintegration and defects. The study also concluded that the average resistivity of the concrete increasing with increasing days with the optimal average resistivity obtained at the 56^{th} day having a resistivity value of 735.06 Ωm compared to the average resistivity on the 1^{st} day having a value of 100.86 Ωm. The concrete pavements with high resistivity have also been stated to inhibit ASR development. Findings from the study showed that the concrete pavements at day 1 are likely to be corrosive but with increasing days and with addition of CBA the corrosive state of the pavement reduces thereby if the pavement is reinforced, CBA becomes helpful in mitigating ASR steel deterioration duce to corrosion. The CBA can be said to limit internal expansion in the concrete pavement which could arise from water ingression and traffic loadings. The study therefore recommends the use of CBA for use in concrete pavement construction as it will help ensure concrete pavements improved performance and durability on the long term.

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