Efficiency of Cow Bone Ash (CBA) In Mitigating Alkali Silica Reaction (ASR) Based On Accelerated Mortar Bar Test (AMBT) In Concrete Pavements

A. Adanikin[1], F. A. Falade[2], A. O. Olutaiwo[3]
1 - Dept. of Civil Engineering, Elizade University, Ilara-Mokin, Ondo State, Nigeria.
2,3 - Dept. of Civil and Environmental Engineering, University of Lagos, Akoka, Nigeria.
Email: nukee02@gmail.com

Abstract: Nigerian roads which are predominantly flexible pavements are in a deteriorated state and requires frequent maintenance before the expiration of their design life. Rigid/Concrete pavements serves as a better alternative to flexible pavements on the long term considering their ability to contain higher traffic load, constructed over a weak subgrade, requiring little maintenance and many much benefits. Concrete pavements however are susceptible to Alkali Silica Reaction (ASR) which compromises the strength and morphological properties of the pavement. This has necessitated studies on the use of supplementary cementitious materials (SCMs) to reduce the effect of ASR and enhance the properties of the concrete pavement. The efficiency of SCMs such as Cow Bone Ash (CBA) to partially replace cement and mitigate the effect of ASR in concrete is researched in this study. This will help reduce the menace of greenhouse gas emission that results from the production of cement required for concrete pavement construction. Concrete bars of known dimensions were constructed with partial replacement of cement by CBA (0%-30%). The expansion of the concrete bars was measured on the 7th, 14th and 28th day of immersion in 1M NaOH. The concrete bars expansion values are then compared to VicRoads 610 and ASTM C1260 standards to determine the concrete reactivity classification. The study revealed that at above 15% CBA replacement levels, cow bone ash is efficient for use in rigid pavements for mitigating the effects of Alkali Silica Reaction. The regression analysis of concrete cubes expansion against percentage of CBA replacement indicates a high level of relationship between both variables. This indicates that the higher the level of CBA addition, the lower the level of concrete expansion and lower level of ASR attack in the Portland cement/rigid pavement. Recommendations on how ASR can be mitigated in new and existing structures are highlighted.

Keywords: Cow Bone Ash (CBA), Alkali Silica Reaction (ASR), Accelerated Mortar Bar Test (AMBT), Concrete Pavements

1.0 INTRODUCTION

The recent move by the Nigerian government to embrace the construction of roads using concrete pavement necessitates the studies about the defects that limit the efficiency of concrete pavements and how to mitigate them. A report by World Health Organization (WHO) in 2015 stated that Nigerian roads are the most dangerous in Africa stating that it has a 33.7% fatality per hundred thousand road users yearly and that road accidents is the third leading cause of death in Nigeria (Iroegbu, 2015). Though other factors such as the recklessness of drivers, poor maintenance of vehicles and the highly deteriorated roads with several bad spots account for these, the use of asphalt roads which is less durable compared to concrete roads contributes to road failure. Due to rigidity and high tensile strength, concrete pavements tends to distribute traffic load over a relatively wide area of sub-grade and the major portion of structural capacity is supplied by the concrete slab itself (Anastasios & Ioannides, 2015). Concrete pavements are used for heavier loads and can be constructed over relatively poor sub-grade (Sanjeev, 2012).

For concrete pavements to achieve the thirty plus + (30+) year service life defined by American Association of State Highway and Transportation Officials (AASHTO) for road pavements, the characterization of the long-term resistance of the concrete to sulfate attack, aggregate reactions, corrosion, and freeze-thaw action is essential. A major cause of road deterioration in concrete pavements is Alkali-Silica Reaction (ASR) that causes expansive swelling and cracks, which expand over time leading to the pavements damage. Several studies have revealed the damaging effects of ASR in concrete pavements. Pereira (2014) revealed that Alkali-Silica reactions are expansive in nature and occur in most Portland Cement Concrete (PCC) and it fracture aggregates and surrounding paste resulting in the concretes cracking, popouts and spalling. Mikata *et al.,* (2012) found that at least 30 cases of fractured bars have been discovered in structures also damaged by ASR and they found that when stirrup fracture is combined with corrosion of the reinforcement, the risk of decreased structural performance is increased. Pyy *et al.,* (2012) found that cracks which originate from ASR are a consequence of swelling from the uptake of water by ASR gel. This cracking is characterized by a network of fine cracks joined up in polygonal shapes and confined by larger cracks in a pattern that resembles the limits in a map and is named 'map cracking'. Also, Blight and Alexander (2011) indicated that mechanical properties are degraded when concrete suffers from ASR.

Supplementary cementitious materials (SCMs) such as CBA can be used to improve concrete performance in its fresh and hardened state as they contribute to the properties of the concrete through hydraulic or pozzolanic activity. They are primarily used for improving the concretes workability, durability and strength. These SCMs materials allow the concrete producer to design and modify the concrete mixture to suit the desired application. Concrete mixtures with high portland cement contents are susceptible to cracking and increased heat generation. These effects can be controlled to a certain degree by using supplementary cementitious materials such as CBA. Studies such as Eme and Ekwulo (2018) revealed that applications of crushed glass in replacing fine aggregates in concrete is limited due to the damaging expansion in the concrete caused by alkali-silica reaction (ASR) between high-alkali pore water in cement paste and reactive silica in the waste glasses. Dickson (2015) stated that all of the Class C fly ash sources tested improved the behavior of the cementitious system, except Muskogee fly ash used at a 20 percent replacement rate and therefore recommended Class C fly ash to mitigate ASR. Adams (2012) posited that supplementary cementitious materials (SCMs) can effectively mitigate ASR in concrete made with Recycled Concrete Aggregate (RCA). A 40% replacement of Portland cement with class F fly ash was able to reduce expansions to below 0.10% in the AMBT for concrete containing 100% of a highly reactive recycled concrete aggregate. In addition, the blend of Portland cement with a class F fly ash (metakaolin) was most effective for both RCAs tested in the study and higher levels of mitigation may be required for some RCAs, compared to the level required to mitigate ASR in concrete made with their original natural aggregates, depending on the age and composition of the RCA. Martin *et al.* (2012) reported a compressive strength gain of 70% for laboratory cylinders that expanded 0.20% from ASR, which they attributed to a "self-healing" effect from continued hydration of cement in the moist storage conditions. Corresponding cylinders affected by Delayed Ettringite Formation (DEF) experienced a similar decrease in compressive strength at much higher expansions (approximately 1.5%); they suggested that the rate of DEF expansion exceeded the rate at which the concrete could heal itself. Okeyinka *et al.,* (2018) stated that the durability performance of CBA under aggressive condition has been analyzed to be more effective at 10% replacement ratio. Adanikin *et al.,* (2019) using electrical resistivity test concluded that ASR and reinforcement corrosion can be effectively controlled between 15% and 20% cement replacement by CBA in concrete/rigid pavements.

Cow bones are readily available as wastes in Nigeria with Lagos alone accounting for more than 6000 slaughtered cattle per day and Nigeria as a whole slaughtering about 90000 cows daily with the country producing 13.8 million cattle yearly (Eze, 2017). This indicates the availability of the cow bones in commercial quantity. Bones generally takes time to decay, which could be millions of years and if not properly disposed off, defaces the environment. Bones have been confirmed as a pozzolanic in nature by researchers such as Falade *et al.,* (2012) thereby making it fit for use in Alkali-Silica Reaction studies. The Accelerated Mortar Bar Test (AMBT) helps to determine the susceptibility of aggregates to alkali attack that leads to expansive reactions and deterioration in concrete. The test also shows a good agreement between supplementary cementitious materials (SCM's) and aggregates by demonstrating a reasonable correlation between the 2-year expansion test (ASTM C1293, 2018) and the 14-day expansion of accelerated mortar bar test ASTM C1260 (2009) making it widely acceptable. This study therefore investigated the application of accelerated mortar bar test in determining the effect of ASR on concrete pavements on addition of CBA at varying percentage replacements; ranging from 0% to 30% over a 28 days' experimental plan.

2.0 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 accelerated mortar bar test (7^{th}, 14^{th} and 28^{th} day).

2.1 Accelerated Mortar Bar Test

The accelerated mortar bar test is predicated on the basis that ASR causes expansion in concrete and this expansion can be used as a measure of the effect of CBA in suppressing ASR. Sodium hydroxide (NaOH) is used in preparing the solution for concrete immersion. Sodium Chloride is used in the accelerated ageing of the concrete sample because it is an activator of alkali which then accelerates the ASR reaction in the concrete.
Molar mass of elemental composition of NaOH (Na – 22.989, O – 15.999, H – 1.008) is calculated as shown in equation 1 and One Molar (1 M) of reagent is added to 2.5 liters of water to determine the required molar mass of NaOH as shown in equation 2.

NaOH = 22.989 + 15.999 + 1.008 = 40 1

Molar Mass of NaOH = 40 * 1M * 2.5 (l) = 100g of NaOH 2

Weight of the samples before and after immersion, the density and change length before and after immersion in concrete were also recorded and this is shown in Table 1. The expansion of the concrete cubes which is an indication of the suppressing effect of Alkali Silica Reaction is calculated by the formula as shown in equation 3:

$$\text{Concrete expansion} = \frac{Length\ of\ Cube\ after\ Test\ (Ln) - Length\ of\ Cube\ before\ Test\ (Lo)}{Length\ of\ Cube\ after\ Test\ (Ln)} \quad 3$$

Concrete bars with expansion values greater than the standard are considered deleterious materials and shows high level of ASR attack. Concrete bars with expansion values equal to the standard are considered slowly reactive to ASR attack. Subsequently, concretes bars with expansion values less than the expansion values are considered free from ASR attack.

3.0 RESULTS AND DISCUSSION

The result assessment is made by measuring the increase in length of representative mortar bars containing with and without CBA, during storage under prescribed test conditions of high temperature. Table 1 shows the changes in weight of the concrete cubes samples before and after immersion in 100g of NaOH at 80°C for 28 days.

Table 1: Accelerated Mortar Bar Test Result Readings

CBA Replacement (%)	Weight of Sample Before Immersion (g)	Weight of Sample After Immersion (g)
0	410	454
5	510	530
10	404	424
15	458	488
20	418	490
30	342	372

Table 2 and 3 shows the obtained and standard specification and classification for ASR expansion in concrete. Figures 1, 2 and 3 shows the changes in expansion of the concrete cubes samples before and after immersion in 100g of NaOH at 80°C at the 7th, 14th and 28th days.

Table 2: Concrete Cubes Expansion Result

CBA Replacement (%)	Concrete Cubes Expansion		
	7th Day	14th Day	28th Day
0	0.050	0.610	0.072
5	0.030	0.034	0.041
10	0.022	0.030	0.034
15	0.013	0.015	0.018
20	0.015	0.017	0.018
30	0.006	0.009	0.013

Table 3: Standard Concrete Reactivity Classification

Mortar Bar Expansion (%) in 1M NaOH (80%)				Classification
VicRoads Standard Specification Section 610		ASTM C1260	ASTM C 1293	
10 Days	**21 Days**	**14 Days**	**28 Days**	
< 0.010*	< 0.010*	< 0.020	< 0.040	Non-reactive
= 0.010*	= 0.010*	= 0.020	= 0.040	Slowly reactive
> 0.010*	> 0.010*	> 0.020	> 0.040	Reactive

*0.015% for naturally occurring fine aggregate

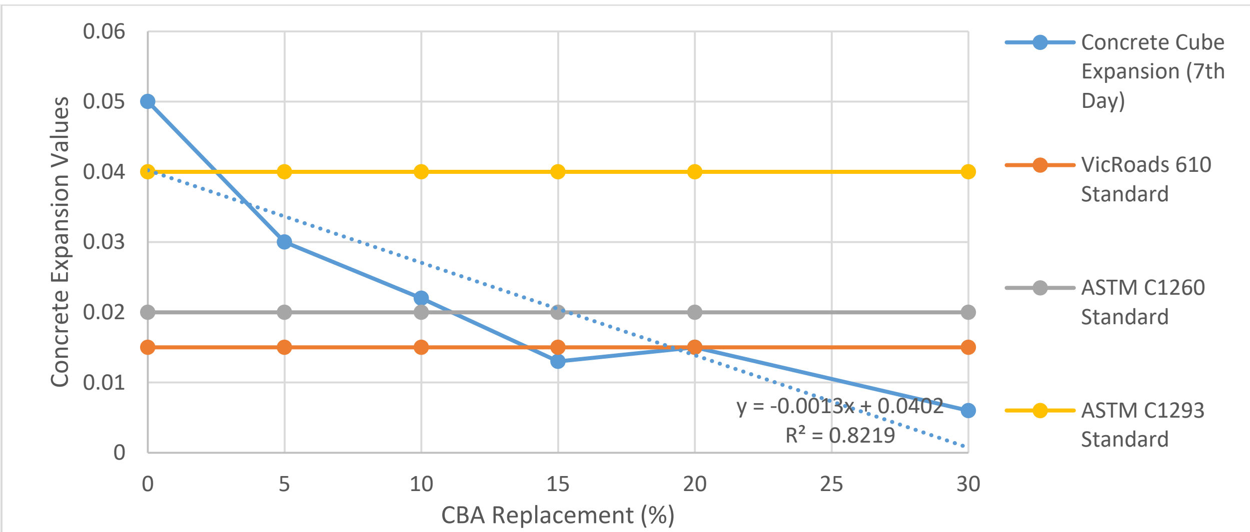

Figure 1: Graph of Concrete Cubes Expansion at the 7th Day

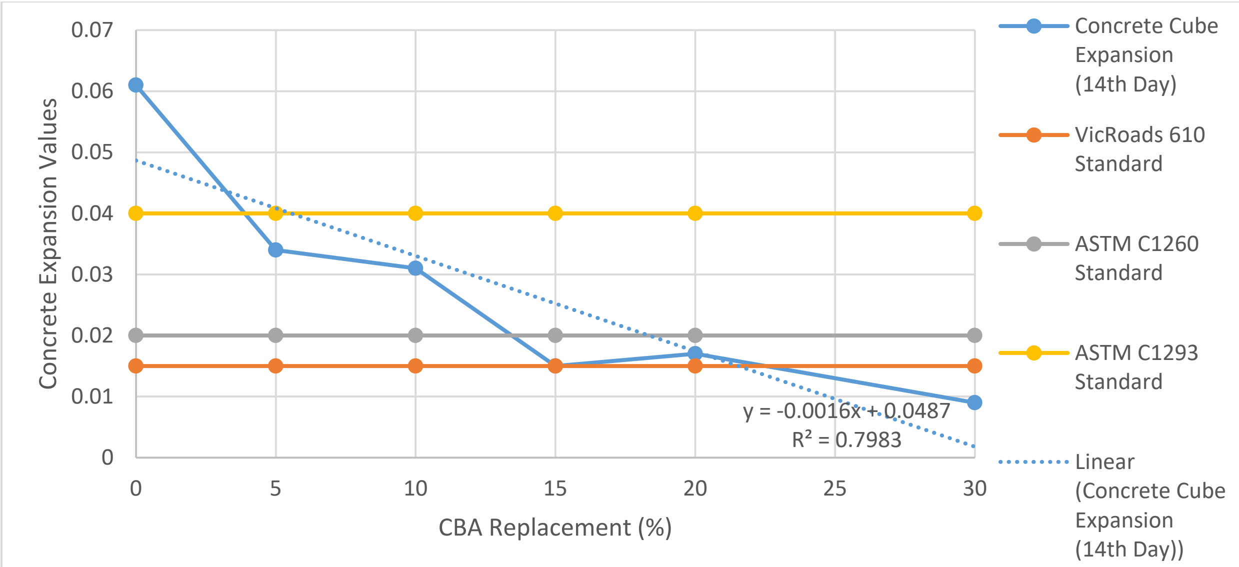

Figure 2: Graph of Concrete Cubes Expansion at the 14th Day

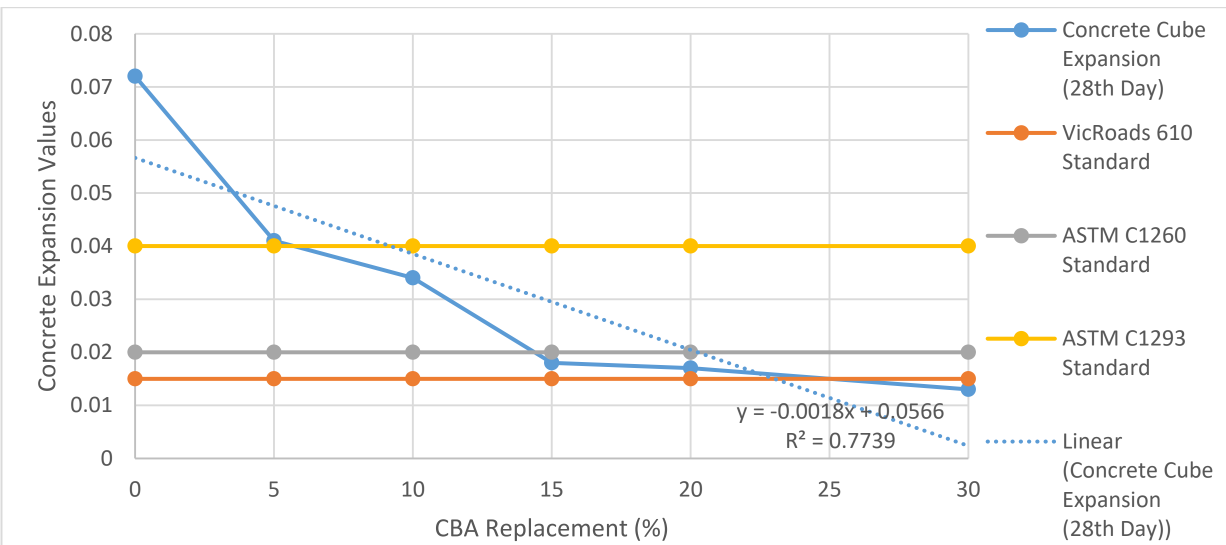

Figure 3: Graph of Concrete Cubes Expansion at the 28th Day

Findings of the study as shown in Table 2 reveals that the expansion of the concrete cube is 0.050, 0.030, 0.022, 0.013, 0.015 and 0.006 at 0%, 5%, 10%, 15%, 20% and 30% CBA replacement levels respectively on the 7th day. The regression relationship y = -0.0013x + 0.0402, shows a R^2 value of 0.8219. Concrete cube expansion values of 0.610, 0.034, 0.030, 0.015, 0.017 and 0.009 at 0%, 5%, 10%, 15%, 20% and 30% CBA replacement levels respectively on the 14th day. The regression relationship y = -0.0016x + 0.0487, shows a R^2 value of 0.7983. For the 28th day, the concrete expansion values are 0.072, 0.041, 0.034, 0.018, 0.018 and 0.013 at 0%, 5%, 10%, 15%, 20% and 30% CBA replacement levels respectively. The regression relationship y = -0.0018x + 0.0566, shows a R^2 value of 0.7739. This indicates a high level of relationship between the CBA addition and concrete expansion.

According to the VicRoads standard specification, concrete cubes with expansion values greater than or equals 0.015 (expansion ≥ 0.015) are considered non- reactive, those with expansion values equals to 0.015 considered slowly reactive and expansion values greater than 0.015 indicates highly reactive concrete. The study reveals that at the 7th day, only the 30% CBA addition concrete bars indicates a non-reactive effect of ASR while the 15% and 30% CBA replacement levels shows a slowly reactive ASR effect. At the 14th and 28th days only the 30% CBA replacement shows a non-reactive concrete bar.

According to the ASTM C1260 which indicates that concrete with greater than 0.02 signifies deleterious materials and highly prone to ASR attack and concretes with expansion values less than 0.02 (expansion < 0.02) are considered free from ASR attack. The study revealed that on the 7th, 14th and 28th days, concrete bars at 15%, 20% and 30% are free from ASR attack. The ASTM C1293 shows that concrete bars of 0.04 (expansion > 0.04) are considered deleterious materials and shows high level of ASR attack and concretes with expansion values less than 0.02 (expansion < 0.04) are considered free from ASR attack. The study shows that at the 7th day, the concrete bars at 5%, 10%, 15%, 20% and 30% CBA replacement levels are non-reactive/non-delirious. The 14th and 28th day results shows that the 0% and 5% concrete bars will be reactive to ASR effect which allows for concrete deterioration.

Table 4 and Figure 4 shows the average concrete cubes expansion results for the experimental days.

Table 4: Average Concrete Cubes Expansion Result

CBA Replacement (%)	Average Concrere Cube Expansion
0	0.061
5	0.035
10	0.029
15	0.015
20	0.016
30	0.009

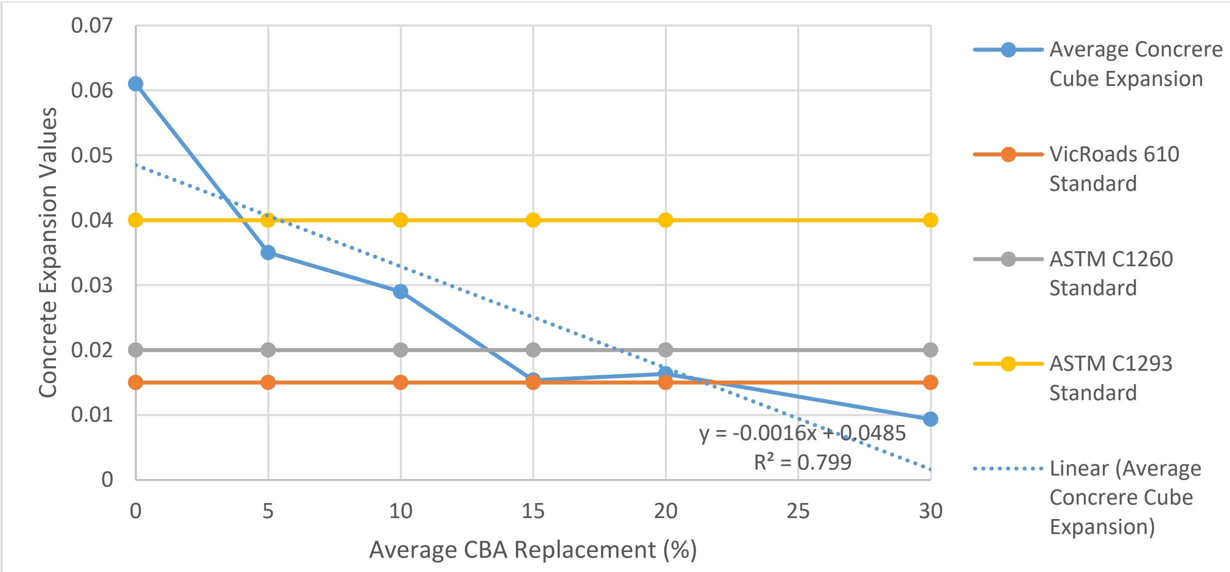

Figure 4: Graph of Average Concrete Cubes Expansion

The average concrete bar expansion is adjudged based on the ASTM C1260 standard considering its value range between the VicRoads and the ASTM C1293 standards. The study revealed that concrete bars with 0%, 5% and 10% CBA replacement had expansion values of 0.061, 0.035 and 0.029. These values are higher than the 0.02 specification. Concrete pavements made from these CBA (0%, 5%, 10%) replacement levels will be delirious concrete and thereby not good to be used in concrete pavement construction as Alkali-Silica Reaction (ASR) is bound to happen especially at the 0% CBA replacement sample.

The study also indicated that concrete bars with 15%, 20% and 30% CBA replacement had expansion values of 0.015, 0.016 and 0.009. These values are lower than the 0.02 specification. Concrete pavements made from these CBA (15%, 20%, 30%) replacement levels are therefore less likely to be susceptible/reactive to ASR. This shows that the 15%, 20% and 30% CBA replacement samples will be good for use in concrete pavements. The study also reveals that the higher the addition of CBA into the concrete samples, the effect of ASR are reduced in the Portland cement/rigid pavements. This is further revealed in Figure 4 where the regression analysis of concrete cubes expansion against % of CBA replacement indicates a high level of relationship between both variables with 79.9% level of relation. This indicates that the higher the level of CBA addition, the lower the level of concrete expansion and lower level of ASR attack in the concrete pavement.

4.0 Conclusion

Roads are highly important infrastructures that are essential for the social and economic growth of any country. Nigerian road pavements however are in such a deplorable state. Majority of Nigerian road pavements are flexible pavements and they are unable to be in good state before their design life elapses and requires frequent maintenance. Rigid pavements though more expensive at initial construction, are able to withstand higher traffic loads, requires lower maintenance and helps in fuel savings for vehicles. Alkali silica reaction however limits the durability and functionality of the concrete. The experimental study employed accelerated mortar bar test (AMBT) to determine the effect of cow bone ash in mitigating ASR in concrete pavements. The study revealed that the addition of cow bone ash as a supplementary cementitious material in concrete pavements helps in mitigating the effect of ASR in concrete pavements. At 15% - 30% CBA replacement the study revealed that the pavement is less likely to be susceptible/reactive to ASR. The analysis of concrete cubes expansion against percentage (%) of CBA replacement indicates a high level of relationship between both variables with 79.9% level of relation. The use of CBA will also lead to reduction in cement production and requirement for concrete pavements constructions. This will therefore help reduce Carbon dioxide (CO_2) and greenhouse gas emission as a result of de-carbonation of limestone in the kiln during manufacture of cement and the combustion of fossil fuel.

Recommendations on how ASR can be mitigated in new and existing structures includes crack filling, restraining or stress relieving actions on the concrete pavement. Crack filling can be for aesthetic purposes, but also works as a sealant for external moisture or chloride ions. Restraining the structure or structural elements is in order to prevent further expansion, or to strengthen or stabilize the structural element. Treating the cause of ASR is the most long-lasting solution but can be time-consuming or difficult to implement on an existing construction. In order to make the chemical expanding reaction to stop, it is necessary to remove one of the driving factors of the reaction, i.e. alkali, silica or water. Chemical treatments or injections, such as use of lithium compounds, can alter the chemical balance in the concrete and this will help to decrease the supply of water in the concrete pavement by controlling the moisture levels and acting as sealants, cladding for the concrete pavement. Substituting a portion of cement with a pozzolan such as cow bone ash (CBA) in concrete mix, reduces the formation of the alkali-silica gel that expands and causes deterioration. The fly ash reacts with calcium hydroxide to produce calcium-silicate hydrates and calcium-aluminate hydrates, rendering less calcium hydroxide for ASR. In proper proportions, this reaction with pozzolans (CBA) reduces the permeability and improves the long-term strength of the concrete pavement.

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