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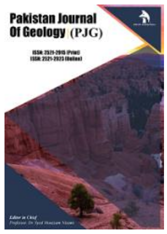

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RESEARCH ARTICLE

PREDICTION OF LOS ANGELES ABRASION FROM SOME PHYSICO-MECHANICAL PROPERTIES

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ABSTRACT

Los Angeles (LA) abrasion test is the best known and most widely applied method used to measure abrasion resistance. However, its preparation phase and execution are expensive and time consuming compared to other mechanical aggregate tests. As such, establishing empirical equations to predict LA abrasion from physical and mechanical methods that are simpler and cheaper to execute provides both time and money savings and is useful for forecasting purposes in preliminary studies. This study aims at obtaining empirical relationships between the LA abrasion and other practical aggregate properties such as aggregate impact value (AIV), aggregate crushing value (ACV), unconfined compressive strength (UCS), specific gravity of the calcareous sandstones collected from four different locations in parts of southeastern Nigeria. The rocks' ACVs and AIVs ranged from 16.34 to 26.29 % and 15.87 to 22.52 % respectively, while the LAAVs varied from 38.62 to 53.1 %. The slake durability index is within the range of 91.1 to 96.7 % and the strength values of the studied rocks fall between 20 to 41 MPa. The correlation plots show that LA abrasion resistance had a very strong linear positive relationship of R^2 = 0.98, 0.74 with the ACV, AIV; a moderate positive relationship (R^2 = 0.49, 0.50) with porosity, water absorption and an inverse relationship with the UCS (R^2 = 0.77), slake durability (R^2 = 0.43), dry density (R^2 = 0.69) and specific gravity values (R^2 = 0.55). Furthermore, the highest correlation coefficient was obtained from the ACV while slake durability recorded the weakest correlation with LA abrasion values. In conclusion, the study suggests that ACV, AIV and UCS tests are the best empirical methods for estimating the LA abrasion value.

KEYWORDS

Los Angeles test; abrasion resistance; empirical relationships; calcareous sandstones

1. INTRODUCTION

Aggregates are essential materials in the construction industry. They are one of the important materials that ensure human well-being. Aggregate quality and strength are frequently measured by their abrasion resistance, which may be evaluated using a variety of test techniques (Erichsen et al., 2008). These testing methodologies simulate at laboratory scale the hardness and abrading of aggregate when subjected to real-world engineering applications. The engineers can then use the information to understand how the aggregates will respond to loading circumstances (Teymen, 2017). A number of test techniques have been developed to examine aggregate behaviour. These techniques include the Los Angeles abrasion, slake durability, and aggregate impact and crushing tests. The Los Angeles test is the most well-known and often used technique for determining abrasion resistance (Ugur et al., 2010; Torok and Czinder, 2017). The test is designed to determine the percentage of wear caused by the aggregates' relative rubbing action with the steel balls employed as an abrasive charge (Khanal and Tamrakar, 2009). The Los Angeles abrasion test is very useful for assessing the aggregates' quality in order to specify their suitable uses particularly in road construction (Ferlund, 2005; Ugur et al., 2010).

However, in comparison to other mechanical aggregate tests, the LA test's preparation and execution are more expensive and time-consuming. The graded aggregate required for the test can be obtained by sifting significant amounts of the aggregate to be tested. In contrast, testing procedures such as AIV, ACV, slake durability, specific gravity, and dry density are fairly straightforward, and the sample size needed in these tests is less when compared to the LA test. Thus, if these rock qualities closely correspond with the LA abrasion value, it may be technically and economically advantageous to utilize these simple test procedures to forecast how an aggregate will perform in a full LA abrasion test.

Correlations between Los Angeles abrasion and other mechanical characteristics of rocks and aggregates have been demonstrated in previously published works. A significant correlation between the LA abrasion and the compressive strength, Schmidt hardness, and point load index was noted by Ugur et al. (2010). As a result, these rock attributes can be utilized to predict the Los Angeles abrasion values of the studied rocks. Oscelik (2011) investigated the relationship between LA abrasion and the mechanical and physical properties of some sedimentary, metamorphic, and igneous rocks. He found a strong association between LA abrasion and Schmidt hardness, unit weight value, point load index, uniaxial compressive strength, and tensile strength in the studied sedimentary rocks. For the metamorphic rocks, the LA abrasion values significantly correlated with Schmidt hardness, point load index, uniaxial compressive strength, and tensile strength, while for the igneous rocks, significant correlations were with Schmidt hardness, apparent porosity, point load index, uniaxial compressive strength, and tensile strength. According to Teymen (2017), the results of the simple and multiple regression analyses indicated a substantial relationship between the LAA and mechanical tests of aggregates. He found that the rock impact hardness number (RIHN), coefficient of rock strength (CRS) and ACV experiments had the strongest associations with LA abrasion levels. A significant inverse link between the LA abrasion values and UCS of the limestones in the Koya area was also noted by (Ismail and Abdulwahid, 2021).

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In correlating the bulk density with the abrasion resistance of some basement rocks stated that any method that would facilitates and expedites the prediction of abrasion resistance, particularly during the reconnaissance stage, should be regarded as essential (Ademeso et al., 2012). The primary goal of this work is to establish empirical connections between LA abrasion and practical mechanical parameters such as AIV, ACV, UCS, and specific gravity of some calcareous sandstones. Establishing empirical equations to predict LAA using basic approaches saves time and money, and is helpful for forecasting in preliminary study.

2. Description of Study Area

The sample locations are situated between latitudes N $05^{0} 57^{i} 21^{ii}$ and N $06^{0} 30^{i} 39^{ii}$ and longitudes E $007^{0} 47^{i} 55^{ii}$ and E $008^{0} 22^{i} 52^{ii}$. The study area falls within the Nigeria's rain forest belt, which is bordered to the north by savannah grassland. Each climate cycle brings two seasons to the area: the wet season (May to October) and the dry season (November to April). The study area is located in Nigeria's subequatorial climate zone, which experiences temperatures between 25 and 30 °C annually and total annual rainfall between 1800 and 2000 mm (Iloeje, 2001).

2.1 Geological Settings

Southern Benue sedimentation began during the Albian period with the deposition of the Asu River Group, which is bordered by mafic volcanics (Uzuakpunwa 1974). However, the arkosic sandstones and conglomerates (Ogoja Sandstones) of continental origin, which lay unconformably on the basement, are thought to be the oldest sediments in the Southern Benue Trough (Hoque and Nwajide, 1984; Uzuakpunwa, 1980). The Asu River Group deposits are composed of shales, siltstones, and limestones, with the occasional occurrence of sandstone rich in ammonites, foraminifers, radiolarians, and pollens from the Albian period. Its thickness is approximately 2000 m (Adighije, 1981). The Eze-Aku Formation was the next to be deposited; although they are commonly thought to be nonconformable, their precise relationship to the Asu River Group is unclear. About 1000 meters of hard, gray, and black calcareous shale and siltstones, thin, sandy, shelly limestone, and calcareous sandstones make up the Eze-Aku Formation. Deposition of the Eze-Aku/Makurdi Formation started in the Upper Cenomanian and it has a Turonian age (Offodile and Reyment, 1977; Cratchley and Jones, 1965; Offodile, 1976; Adighije, 1981). The Awgu Formation, located above the Eze-Aku/Makurdi Formation, is composed of marine fossiliferous, grey bluish shales, limestones, and calcareous sandstone that is most likely Late Turonian to Coniacian in age (Offodile, 1976). It comprises of a limited band of fine to medium-grained, moderately cemented sandstone known as the Agbani Sandstone and the Akpoha Sandstone, respectively (Agagu and Adighije, 1983; Petters, 1978; Ojoh, 1990). The Turonian-Coniacian depositional cycle includes the transitional marine Eze-Aku and Yolde Formations, as well as the marine Awgu and Pindiga Formations, which reflect the aulacogens' downwarping stage (Abubakar et al., 2010, Aminu et al., 2017, Obaje, 2009, Ogunmola and Olobaniyi, 2020). The Turonian-Coniacian depositional cycle was terminated by a phase of deformation and compressional folding that was evidently developed during the Santonian. Intense and widespread anticlines and synclines, such as the Abakaliki anticlinorium, were the outcome of this event (Burke et al., 1972). The Nkporo Shales are the Campanian sediments that sit on top of the Awgu Formation. The Nkporo Shales unit is unconformably overlain by dominant sandstone, carbonaceous shales, sandy shales and local coal seams which, together form the Mamu Formation (Cratchley and Jones, 1965; Offodile, 1976; Kogbe, 1981). The Mamu Formation is about 400 m thick and is overlain by 330 m of coarse-grained, typically current-bedded sandstones known as the Ajali Formation (Offodile, 1976). Above the Ajali Formation, a thin layer of what is generally considered to be the most recent sediments in the Lower Benue area was deposited; the Nsukka Formation and is composed of carbonaceous shales, sandstones, and coal seams. It dates from the Late Maastrichtian to the Early Palaeocene. The Subsurface stratigraphic cross-section of Benue trough highlighting its lateral continuations across the trough is depicted in Figure 1.

The rock samples used in this study were collected from the Amasiri Sandstone of the Eze-Aku Group and the Cretaceous sediments area of the Asu River Group. The Amasiri Sandstone is made up of shale, calcareous shale and sandstone, whereas the Asu River Group comprises of mudstones and sandstones (Ekwueme, et al., 1995).

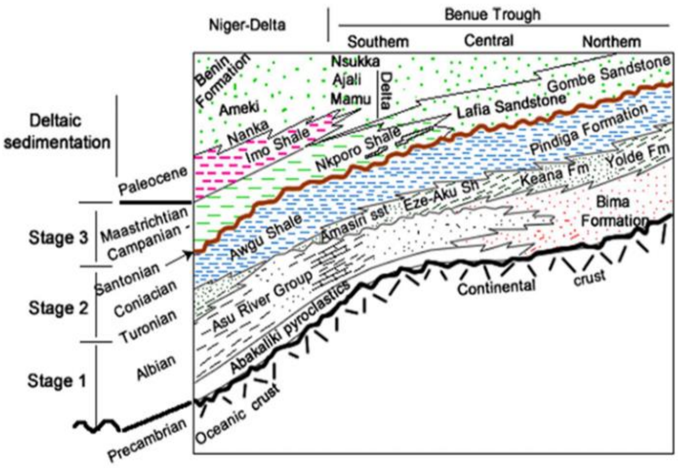

Figure1: Subsurface stratigraphic cross-section of Benue trough highlighting its lateral continuations across the trough (Ibe and Okon, 2021; Nwajide, 2013)

3. Materials and Methods

3.1 Sampling

The rock blocks that were cored and crushed into aggregates were obtained from quarries and natural outcrops around the southern Benue Trough in Nigeria. The laboratory study was conducted on calcareous sandstones from four different locations. For each rock property, multiple tests were performed, and mean values were calculated.

3.2 Experimental Studies

3.2.1 Dry Density and Specific Gravity

The dry weight (after 24 hours of oven drying at 110°C and 30 minutes of cooling) and saturated surface dry mass (after 24 hours of immersion in water) were measured using an electronic weighing scale with an accuracy of 0.01. Each aggregate's unit volume weight was calculated by dividing its dry weight by its volume. The effective porosity value was derived as the ratio of the pore volume to the bulk volume of the sample. The pore volume of the sample was estimated using the weight difference between the saturated weight (surface dry) and the dry sample weight. The water absorption of the sample was calculated as a percentage of its dry weight using the weight difference between its dry weight and its saturated surface dry weight. The dry density (ρdry), saturated density (ρsat), specific gravity (G_S) was calculated using the following relation in Eqn. 1-5:

$$\rho dry = Ms/V \quad (1)$$

$$\rho sat = Msat/V \quad (2)$$

$$G_S = \frac{Ms}{Msat - Msw} \quad (3)$$

$$n = (Msat - Ms)/\rho w/V * 100\ \% \quad (4)$$

$$WAC = (Msat - Ms)/Ms * 100\ \% \quad (5)$$

where M_s is the solid mass of specimen, M_{sat} is the surface-dry saturated mass, Msw is the mass of solid in water, ρw is the water density and V is the bulk volume.

3.2.2 Los Angeles Abrasion Test

The irregular samples for aggregate degradation testing were broken into the required size using a jaw crusher. The LAAV test was carried out in line with ASTM C131/C131M-14. Aggregate Grade B was used because it was comparable in size to the aggregate used for ACV and AIV. Each sample had an aggregate mass of around 5000 ± 10 g. The LAAV was calculated as a percentage of the initial mass of the tested sample after 500 revolutions using the following equation 6:

$$LAAV = \frac{\text{Initial mass} - \text{Final mass (after 500 revolutions)}}{\text{Initial mass}} * 100\% \quad (6)$$

3.2.3 Aggregate Impact Value

The aggregate impact value test (AIV) evaluates aggregate strength and provides a relative indicator of resistance to granulation or pulverization as well as abrupt shock or impact. Samples in the size range of 10–14 mm, which is typical of asphalt road wearing courses are used for the test. The device utilized is relatively portable and inexpensive to run, allowing for aggregate testing in both laboratories and in the field (Koukis et al., 2007). According to BS-812 (1990a), a hammer weighing roughly 14 kg (13.5–14 kg) is dropped 15 times on the aggregate from a height of roughly 381 mm (381±6.5 mm) as part of the AIV test.

The AIV is the mass of fine material that passes through the #8 (2.36 mm) sieve as a percentage of the sample's initial weight. It is calculated using Eqn. 7

$$AIV = \frac{A - B}{A} * 100\% \quad (7)$$

where A is the initial mass of rock aggregates, and B is the final mass remaining on the #8 sieve after impact load for AIV test.

3.2.4 Aggregate Crushing Value

ACV measures the relative resistance of an aggregate to crushing under a gradually applied compressive load. In the ACV test, continuous loading is applied gradually until a total load of approximately 40 tons is achieved in 10 minutes (BS-812, 1990b).

The ACV value is the mass of fine material that passes through the #8 (2.36 mm) sieve expressed as a percentage of the sample's original weight. It is calculated using Equation 8.

$$ACV = \frac{C - D}{C} * 100\% \quad (8)$$

where C is the initial mass of rock aggregates, and D is the final mass remaining on the #8 sieve after impact load for AIV test or crushing load for ACV test.

3.2.5 Uniaxial Compressive Strength Test

The UCS testing was performed on fresh cylindrical cores free from macroscopic defects. The core samples have a diameter of 40 mm and a length to diameter ratio of 2.5:1 was maintained during the UCS testing.

3.2.6 Slake Durability Test

Testing for slake durability was standardized in accordance with ASTM, D4644-16, 2016. In order to perform the slake durability test, an oven-dried sample of 10-12 pieces, each weighing 40-60 g, for a total weight of roughly 450 to 500 g, are placed in a 2 mm-meshed drum and rotated through water for ten minutes at a fixed speed. After being oven-dried, the sample that is still in the drum is weighed. The weight of the remaining sample divided by the initial weight multiplied by 100 is the slake durability index (I_d). The test is conducted again on the remaining sample to calculate the second-cycle slake durability index (I_{d2}).

4. Results and Discussion

The Los Angeles abrasion and some mechanical and physical parameters of the studied calcareous sandstones have been found to be related through the use of simple regression analysis. The Los Angeles abrasion value, aggregate impact, and aggregate crushing values showed a strong positive linear association. Figure 2a and 2b show that LAAV increased linearly alongside increases in AIV and ACV. A significant positive connection ($r^2 = 0.98$) exists between LAAV and ACV (Figure. 2a). The correlation between the LA abrasion value and the ACV is consistent with the findings of Teymen (2017) who also noticed that the ACV is one of the best empirical methods for determining the LA abrasion value. Figure 2b depicts the estimated AIV-LAAV relationship based on the test results obtained from the current investigation. The correlation is linear, with a high correlation coefficient ($R^2 = 0.74$). The correlation between the resistance values (LAAV and ACV, AIV) and their coefficients for the studied calcareous sandstones is expressed in Eqns. 9 and 10:

$$LAAV = 1.4111\ ACV + 15.552 \quad (R^2 = 0.9878) \quad (9)$$

$$LAAV = 1.8657\ AIV + 8.283 \quad (R^2 = 0.74) \quad (10)$$

The relationship between the UCS and LAA was displayed in Figure 2c. The correlation plot showed that they had a strong negative linear association ($R^2 = 0.77$) with one another. This suggests that that the harder the rock, the less it abrades under the LA test. This relationship is similar with the findings of writers such as Kahraman and Fener 2007; Ugur et al. 2010; Ozcelik 2011; and Czinder et al. 2021, who found a strong inverse link between LAAV and uniaxial compressive strength. Furthermore, a weak inverse relationship ($R^2 = 0.43$) between LAA and slake durability was observed (Figure. 2d). According to Koukis et al. (2007), the durability of rocks in terms of resistance to weathering is directly proportional to their resistance to wear, and both are controlled by the volume of pore spaces. Therefore, a rock with low weathering resistance would also have low wear resistance, which would ultimately result in a higher LA abrasion value. The regression equation and correlation coefficients relating UCS and slake durability with the LA abrasion is shown in Eqn. 11 and 12

$$LAAV = -0.6377\ UCS + 63.553 \quad (R^2 = 0.77) \quad (11)$$

$$LAAV = -1.4055\ SD + 176.56 \quad (R^2 = 0.43) \quad (12)$$

Porosity and AAV have a direct relationship (Figure. 2e), indicating that resistance to mechanical wear decreases as porosity increases. The porosity of an aggregate is inversely related to its strength. The presence of voids affects the strength of an aggregate because stress concentrates around these spaces. The volume of pore spaces constitutes significant geological factors influencing soundness and abrasion resistance. Water absorption capacity and LA abrasion values show a significant positive connection ($R^2 = 0.5$). Figure 2f shows increasing water absorption is related to an increase in the LAAV. This demonstrates that relatively more porous aggregate is easily broken, resulting in poorer impact resistance for the material (Krynine and Judd,1957; Afolagboye et al., 2015).

$$LAAV = 1.4274\ n + 34.743 \quad (R^2 = 0.49) \quad (13)$$

$$LAAV = 3.2167\ WAC + 35.313 \quad (R^2 = 0.50) \quad (14)$$

There is a noteworthy positive association between LAA and specific gravity and dry density. The R^2 value of 0.69 derived from corelating dry density with the Los Angeles abrasion indicates a high negative correlation. This is in collaboration with the opinion of Ademeso et al., 2012 who pointed out the potency of influence the density of a rock can have on their abrasion resistance. The specific gravity of a rock reflects the quantity of heavy minerals it contains. The negative correlation between specific gravity and LA abrasion resistance demonstrated the significance of mineralogy in the rock's abrasion resistance. The stronger the mineral content in a rock, the lesser the degradation that will be recorded. The trend line connecting the LA abrasion resistance with the dry density and specific gravity is shown in Eqns. 15 and 16.

$$LAAV = -51.13\ DD + 170.07 \quad (R^2 = 0.69) \quad (15)$$

$$LAAV = -48.221\ SG + 164.82 \quad (R^2 = 0.55) \quad (16)$$

5. Conclusion

Regression analysis was used to assess the relationship between the Los Angeles abrasion resistance and some physicomechanical properties of calcareous sandstones in the southern Benue Trough. The materials analyzed are calcareous sandstones from four different locations. The research findings can be stated as follows:

- LA abrasion resistance showed a linear positive relationship with the ACV, AIV, Porosity and WAC but showed an inverse relationship with the UCS, Slake durability, dry density and specific gravity values.
- The correlation coefficients obtained from the equations attempting to predict the LA abrasion resistance varied between 0.43 and 0.98. The highest correlation coefficient was obtained of 0.98 from the ACV test while slake durability test recorded the weakest correlation coefficient of 0.43.
- A model generated from the relationship with ACV (LAAV = 1.4111 ACV + 15.552) is therefore recommended for predicting LA abrasion values.

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