Journal of
Applied Geographical Studies
(JAGS)

Geotechnical Properties and Aggregate Quality Assessment of Marl Deposit in Afikpo Area, Southeastern Nigeria

Geotechnical Properties and Aggregate Quality Assessment of Marl Deposit in Afikpo Area, Southeastern Nigeria

*1Sunday, E.U., [2] Owonaro, B.J., [3] Okeke, O.C., [4] Amadi, C. C., [5] Okonkwo, S. I., [6] Ofoh, J. I., [7] Iwuoha, P. O.

[1-7]Department of Geology, Federal, University of Technology, Owerri, Nigeria,

*Corresponding Author's E-mail: elizabethsundayuz@gmail.com

Abstract

Purpose: Marl is an impure limestone that is generally not good for cement production because of its low calcium carbonate content. Aggregates derived from marl deposit in Afikpo Area, Southeastern Nigeria, are currently being used in construction of concrete structures and highway pavements by construction companies and individuals. There is no published information on the suitability of the aggregates for such uses. The purpose of this study was to determine the suitability of the aggregates as components of concrete and highway pavements in terms of satisfying the non-swelling and acceptable strength characteristics / requirements.

Methodology: Geotechnical tests including Atterberg limits (liquid limit, plastic limits and plasticity index), linear shrinkage and free swell were used to evaluate the swelling characteristics; while physico- mechanical tests including specific gravity, water absorption. Aggregate Crushing Values (ACV), Aggregate Impact Value (AIV) and Los Angele Abrasion Value (LAAV) were used to evaluate the strength characteristics. The field studies indicate that the marl deposit is associated with Ezeaku Formation of Lower Benue Trough.

Results: Results of geotechnical tests indicate liquid limit, plasticity index, linear shrinkage and free swell values of 29.50%, 4.60%, 0.36% and 10.00%, respectively. Similarly, results of physico-mechanical tests indicate specific gravity, water absorption, ACV, AIV and LAAV values of 2.58%, 1.90%. 23.50% 29.45% and 42.70%, respectively.

Unique contribution to theory, practice and policy: Since the results satisfy the non-swelling characteristics (plasticity index < 12%, linear shrinkage < 8% and free swell < 50%) and acceptable strength characteristics (water absorption < 3%, ACV < 30%, AIV < 30% and LAAV < 45%) requirements for good concrete and highway pavement aggregates, aggregates derived from marl deposit in Afikpo Area, Southeastern Nigeria, are strongly recommended to be used as aggregates in concrete and highway pavement construction.

Keywords: *Marl deposit, aggregates, physico-mechanical, Atterberg limits, highway pavement and geotechnical*

Journal of Applied Geographical Studies
ISSN 2958-7433 (online)
Vol.1, Issue No.1, pp 15–30, 2021

1.0 Introduction

The increasing demand for construction aggregates has necessitated the sourcing of other alternative aggregates to the conventional granite and other igneous and metamorphic aggregates to the conventional granite and other igneous and metamorphic aggregates. (Bell, 2007; Akpokodje, 1992; Braithwaite, 2005). Marl is a calcium carbonate or lime rich mud or mudstone with variable amounts of silt and clay. (Cripps et al., 1992; Bell, 2004). The marl deposits of the Ezeaku Formation exposed around the Amasiri-Akpoha axis has been quarried both locally and commercially for its aggregate quality (Nwajide, 1990; Akpokodje, 1992). Marls are not generally suitable for production f cement because of their low calcium carbonate content. But they may be used as aggregates in highway pavements and concretes, and as facing stones in buildings.

Studies have shown that properties of an aggregate such as mineral composition, texture, roughness, swelling potential and strength can affect the performance of the aggregate (Farmar, 1983; James, 1993). Limestone is a good construction aggregate material owing to its low alkali-silica ratio and textural quality. (Krynine and Judd, 1957; Goodman, 1993)

The depositional model for the Amasiri Sandstone of the Ezeaku Formation, southern Benue Trough has been controversial. The sandstones have been variously interpreted as tidal/subtidal shallow marine deposits, storm-dominated shallow shelf deposits shelf to deep water environment (Igwe and Okoro, 2016).

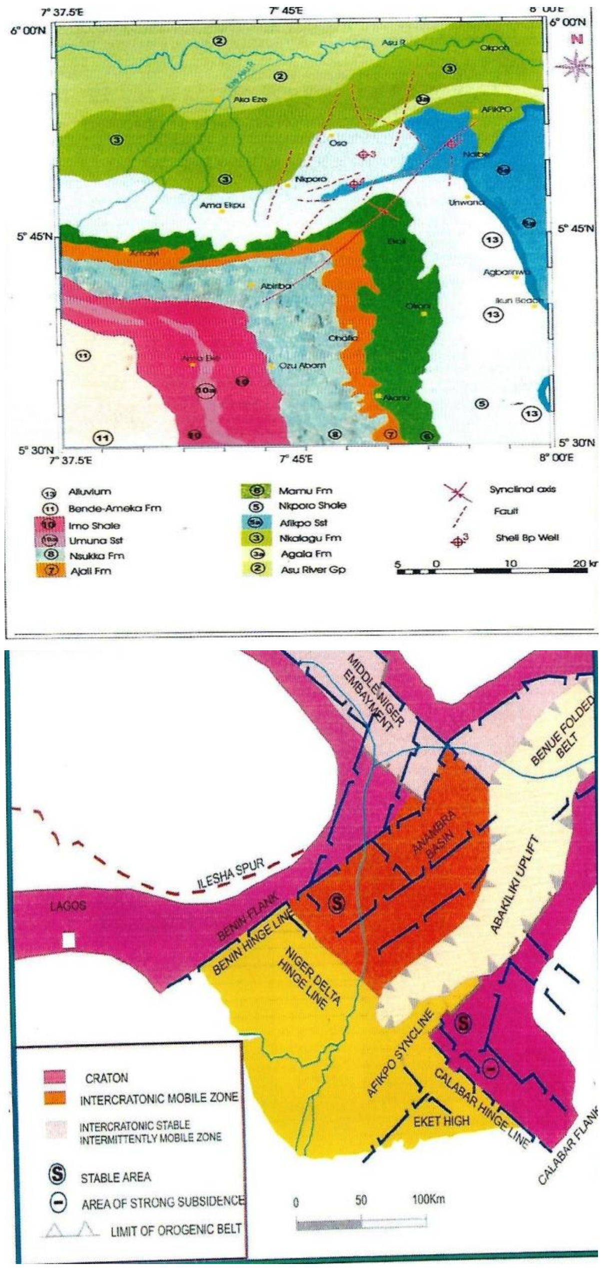
Marl has extensively been used as aggregates for both concretes and highway pavements within the study area, it becomes imperative that since they are geological materials; hence, a study to investigate or understand the geotechnical properties and quality of aggregates. The geotechnical characteristics influence the swelling potential while the physico-mechanical characteristics influence the strength/quality of the aggregates.

The present study involves determination of geotechnical properties of the marl deposit associated with the Ezeaku Formation in Afikpo area, and assessment of the marl as rock aggregate for engineering purposes (concrete production and highway pavement construction).

2.0 Location and Geology of the study Area

The study area covers approximately 461.2km2 is located between Latitudes 5˚51ˈN and

6˚009ˈN, Longitudes 7˚45ˈE and 8˚00ˈE (Fig. 1). The area includes the following communities: Amasiri, Akpoha, Ibii, Mgbom, all in Afikpo. The study area lies within the Ezeaku Formation for which consists of feldspathic sandstones, laterally alternating with marine shales and limestone lenses (Reyment, 1965). In the Afikpo area, the dominantly shally Ezeaku Formation changed facies to a sequence of sandstones interbedded with shales and minor limestones referred to as the Amasiri Sandstone (Whiteman, 1982).



(a) (b)

Fig. 1: The Geological map of study area showing (a) Structural features and (b) Afikpo Syncline (Murat, 1972; Umeji, 2010)

The geologic and tectonic evolution of the area can be traced to the Benue Trough. The Benue Trough is a northeast – southwest trending intracontinental basin that connects the east with the

Journal of Applied Geographical Studies
ISSN 2958-7433 (online)
Vol.1, Issue No.1, pp 15–30, 2021 www.carijournals.org

African rift system through the Bornu Basin (Olade, 1975; Burke *et al.,* 1972; Benkhelil, 1986). The first mantle plume and associated events that led to the evolution of the Benue Aulacogen is believed to have taken place during Aptian times and was associated with the emplacement of the alkaline – mafic lavas and volcaniclastics (the Abakiliki pyroclastics) as well as the deposition of the Asu River Group (Olade, 1975). Temporary cessation or reduction in the Trough became the principal cause of deformation (folding) of the Albian sediments. This was accompanied by marine regression that led to the deposition of the Odukpani Formation only in the Calabar Flank during the Cenomanian. Mantle upwelling became reactivated during the Turonian and rifting along earlier lines of weakness allowed for unstable conditions that led to the deposition of the Ezeaku Formation, unconformably on the folded Asu River group (Nwachukwu, 1972; Olade, 1975). The final stage in the tectonic evolution of the Benue Rift/ Aulacogen occurred when the mantle upwelling ceased or there was an eastward migration of the plume relative to the continent in the Senonian. This led to sub – crustal contraction, final collapse of the Trough and a broad asymmetric downwarp (Nwachukwu, 1972) which led to a widespread Compressive deformation of pre–Santonian rocks within the Trough.

Table 1: Correlation Chart for Early Cretaceous Tertiary Strata in the Southeastern Nigeria (Nwajide, 1990).

<table>
<tr><th colspan="2">AGE</th><th>ABAKILIKI-ANAMBRA BASIN</th><th>AFIKPO BASIN</th></tr>
<tr><td>m.y
30</td><td>Oligocene</td><td>Ogwuashi-Asaba Formation</td><td>Ogwuashi-Asaba Formation</td></tr>
<tr><td>54.9</td><td>Eocene</td><td>Ameki/Nanka Formation/Nsugbe Sandstone (Ameki Group)</td><td>Ameki Formation</td></tr>
<tr><td>6.5</td><td>Paleocene</td><td>Imo Formation</td><td>Imo Formation</td></tr>
<tr><td>73</td><td>Maastrichtian</td><td>Nsukka Formation
Ajali Formation
Mamu Formation</td><td>Nsukka Formation
Ajali Formation
Mamu Formation</td></tr>
<tr><td rowspan="2">83
87.5</td><td>Campanian</td><td>Nkporo Formation / Enugu Shale</td><td>Nkporo Shale /
Afikpo Sandstone</td></tr>
<tr><td>Santonian</td><td rowspan="2">Agbani Sandstone /Awgu Shale</td><td>Non-deposition / Erosion</td></tr>
<tr><td rowspan="2">88.5</td><td>Coniacian</td><td rowspan="2">Ezeaku Group (Incl. Amasiri Sandstone)</td></tr>
<tr><td>Turonian</td><td>Eze Aku Group</td></tr>
<tr><td>93
100</td><td>Cenomanian
Albian</td><td>Asu River Group</td><td>Asu River Group</td></tr>
</table>

Journal of Applied Geographical Studies
ISSN 2958-7433 (online)
Vol.1, Issue No.1, pp 15–30, 2021 www.carijournals.org

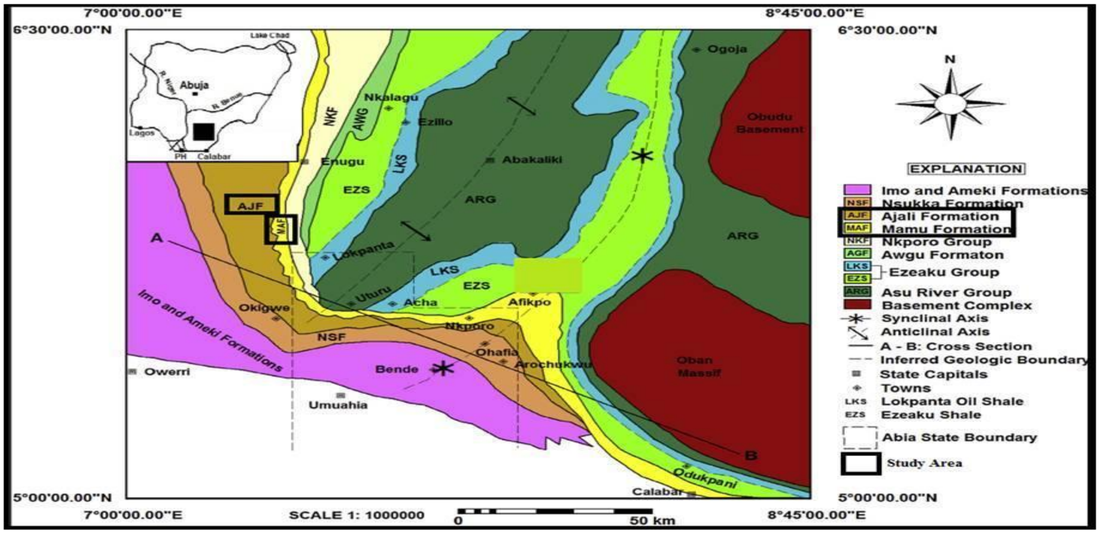


Fig 2: Regional geologic map of the southern Benue Trough (Modified after Igwe and Okoro, 2016)

3.0 Materials and Methods

3.1 Field Studies and Sample Collection

The field studies comprise a geological mapping of the study area. The mapping was completed within subsequent field trips for about four times and was basically aimed at examination of outcrop sections, the lithologic relationship in the outcropping profile, the nature of contacts, and the sedimentary structures. The attitude of the bed and other structural features were measured with the aid of Brunton/Silver compasses, while steel tape was used to measure the vertical thickness of the units. A geologic hammer was used for collection of samples followed by labeling and packaging. Aggregates were collected from outcrops in the study area. The Techniques for sample collection follows that of US Bureau of Reclamation (USBR) (1963).

Fig 3: Sample Collection at the Study Area

3.2 Laboratory Tests on Samples

3.2.1 Geotechnical Tests

The geotechnical tests performed on the samples include Atterberg limits (liquid limit, plastic limit and plasticity index), linear shrinkage and free swell. Liquid limit and plastic limit were measured according to guideline by British Standard (BS) 1137 (1975), Krynine and Judd (1957), while linear shrinkage was measured according to guideline by Attimeyer (1956), Heidema (1957) and Singh (1992).

The free swell was measured according to guideline by Dawson (1956), Krynine Hardcastle (2003) and Krynine and Judd (1957).

The details of the measurements are shown below:

I. Liquid limit (BS 1137, 1975)

About 200 gm of quarry dust is mixed with distilled water to form a uniform paste, the dust should be that which passed through sieve No 425µm. A portion of the sample (wet) is placed in a casagrande cup half-filled, and the top bucked up pararell to the base. A groove of 2mm is cut through the center of the portion of the wet sample in the casagrande cup or dish with a grooving tool. The cup is lifted 10mm and dropped onto a rubber base until the bottom of the groove had closed over a length of 10mm, the number of blows at which the groove closes is recorded. This procedure is repeated to four times to obtain various numbers of blows, for each of the grooves in casagrande cup samples that was collected for moisture content determination.

II. Plastic limit (BS 1137, 1975)

About 200 gm of quarry dust is mixed with distilled water to form a uniform paste, the dust should be that which passed through sieve No 425µm. A portion of the sample (wet) is placed in a casagrande cup half-filled, and the top bucked up pararell to the base. A groove of 2mm is cut through the center of the portion of the wet sample in the casagrande cup or dish with a grooving tool. The cup is lifted 10mm and dropped onto a rubber base until the bottom of the groove had closed over a length of 10mm, the number of blows at which the groove closes is recorded. This procedure is repeated to four times to obtain various numbers of blows, for each of the grooves in casagrande cup samples that were collected for moisture content determination.

III Linear shrinkage (Attimeyer, 1956, Single, 1992)

Linear shrinkage is an indirect method of estimating shrinkage limit. It is the decrease in one dimension of a soil sample, expressed as a percentage of the initial dimension when moisture content is reduced from a given value to the shrinkage limit. This test was done by putting the moist sample in the linear shrinkage bar that is about 14cm in length and allowed for 24hours, if the water content is sufficient to fill the pores when the sample is at its minimum volume attained by drying.

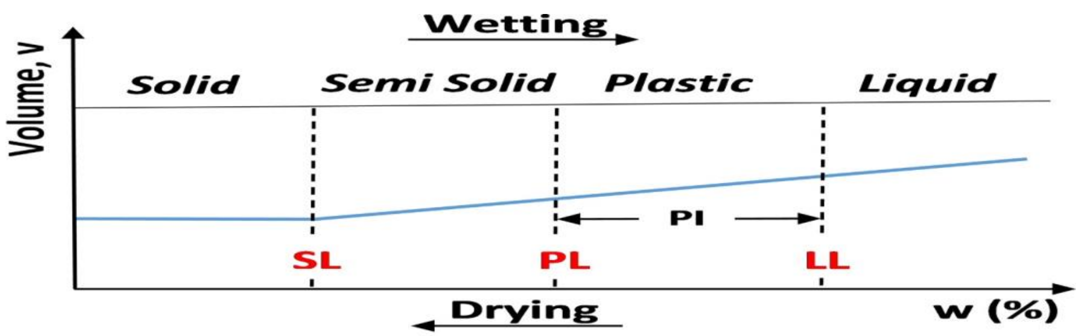


Fig 4: Relationships between liquid limit, plastic limit and shrinkage limit

IV Free swell (Krynine and Judd, 1957; Hardlcastle, 2003)

Free swell determines the swelling potential and degree of expansion classification of expansive soils. The free swell test was determined in accordance with the method given by Krynine and Judd (1957) for the clay content in a given rock. The Quarry dust put into the cylindrical tube and distilled water added. The same procedure is done for kerosene and kept for 24hours to determine the clay content.

3.2.2 Physico-Mechanical Tests

The physico-mechanical tests performed on the aggregate sample include specific gravity, water absorption, Aggregate Crushing Value (ACV) Aggregate Impact Value (AIV) and Los Angele Abrasion Value (LAAV). These tests were performed in accordance with specifications of O'Flaharty (1974) and Clultterbuck *et al.*, (1982).

The details are shown below:

I Specific Gravity Test and Water Absorption test

Journal of Applied Geographical Studies
ISSN 2958-7433 (online)
Vol.1, Issue No.1, pp 15–30, 2021 www.carijournals.org

The test we performed by immersing aggregate sample (20 to 32mm) in distilled water and enclosed in a wire-mesh container for 24 hours. The container with the aggregate is weighed when immersed in water, thus giving it a buoyant weight. The material is then surface-dried and weighed in air, giving the saturated weight (MS), thereafter the material is oven-dried at a Temperature of 100-1100c and dry weight is determines (MD). The specific gravity of a solid is the ratio of its mass to that of an equal volume of distilled water at a specified temperature. About 15 to 25 mm (348 g) of weight of aggregates sample, empty pyconometer and water were recorded as (M_3). Weight of pyconometer and aggregates were recorded as (M_2), weight of pyconometer and water recorded as (m4) while the weight of empty pyconometer was recorded as (M1).

II Aggregate Crushing Value Test

The test consists of subjecting the specimen of aggregate ranging between 20 to 32mm in standard mould to a compression test under standard load conditions. Dry aggregates (between 100 to 1100c temperature) passing through 32mm sieves and retained 19.5mm sieves are filled in a cylindrical measure of 11.5. Load is then applied through the plunger at a uniform rate of 4 tonnes per minute, until the total load is 40 tonnes and then the load released. Then crushed aggregates are removed from cylinder and sieved through 2.36 mm sieve and weight of passing material (**W2**) is expressed as the percentage of the weight of the total sample (**W1**) which is the aggregate crushing value. This indicates the ability of an aggregate to resist crushing under a gradually applied compressive load.

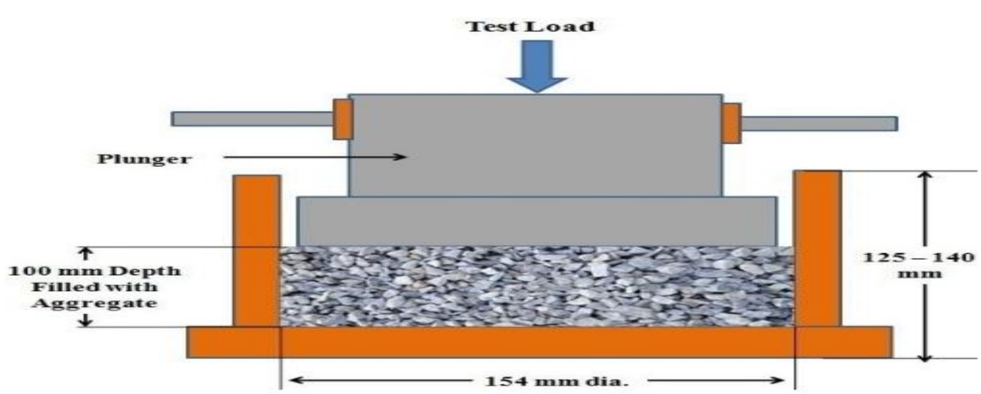
ACV = W1/W2 *100

<10% are considered very strong

10-20% is considered strong

20-30% are just good enough for road stones (Sigh, 1991)

Materials with low ACV are generally preferred to be used for highway pavements



Aggregate Crushing Value Mould

Journal of Applied Geographical Studies
ISSN 2958-7433 (online)
Vol.1, Issue No.1, pp 15–30, 2021 www.carijournals.org

Fig. 5: Pictorial representation showing ACV Mould

III Aggregate Impact value test

Aggregates may be air dried or oven heated at 100 to 1100c for a period of hours and passed in 12.5 mm sieve and retained on 10 mm sieve is filled in a cylindrical steel cup of internal diameter 10.2 mm and depth 5 cm which is attached to a metal base of impact testing machine. The material for about 350g is filled in 3 layers where each layer is tamped for 15 numbers of blows. Metal hammer of weight 13.5 to 14 Kg is arranged to drop with a free fall of 38.0 cm by vertical guides and the test specimen is subjected to 15 numbers of blows.

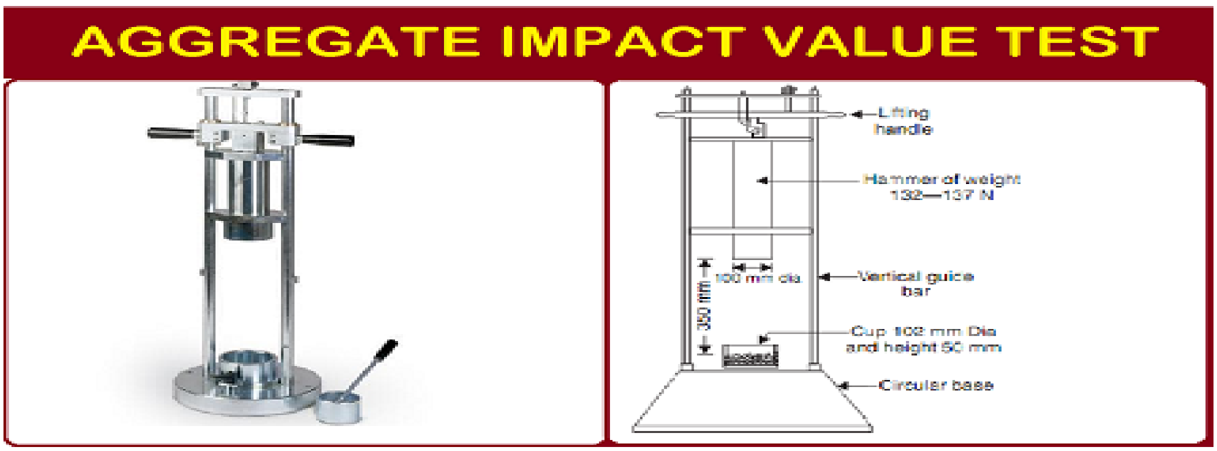


Fig. 6: Pictorial representation showing Aggregate Impact Value Test

IV Los Angeles Abrasion test

About (5000) gm (W_1) of the aggregate ranging from 20 to 32mm in the oven for drying. Open the Los Angeles equipment and put the dried aggregate sample with the (10) balls in it and close it again. After specified revolutions of about 30 per minute for 500 revolutions at the completion of the test, the material is sieved through 2.36 mm sieve and passed fraction is expressed as percentage total weight of the sample. This value is called Los Angeles abrasion value. This is preferred for carrying out the hardness property. This is done by finding the percent wear due to relative rubbing. LAAV is a measure of resistance to attrition .The acceptable limits for highway pavement is <40%. The lower the value of the LAAV the greater it's resistance.

4.0 Results and Discussion

4.1 Presentation and Interpretation of Results

Tables 2 and 3 are results of geotechnical tests and guidelines for the interpretation of results while table four is the result and interpretation guideline of physico-mechanical tests.

Table 2: Result of Atterberg Limit, Linear Shrinkage and Free Swell Values

Sample no	Liquid limit %	Plastic limit %	Plasticity index%	Moisture Content %	Linear Shrinkage %	Free Swell
MA.1	29.50	24.90	4.60	30.0	0.30	10

It is observed that all the samples gotten from the study are non- plastic, meaning the soil has little or no plasticity. The plasticity index is also low.

Table 3. Guidelines for Swelling Potential and Degree of Expansion Classification of Expansive Soil Based on Various Geotechnical Parameters.

Swelling Potential Classification					
S/No.	**Parameter**	**Values**	**Classification**	**Test Results**	**Remarks**
1	Plasticity Index (%) (Ola, 1981)	<15	Low	4.60%	Non plastic
		15 – 25	Medium		
		25 – 35	High		
		>35	Very High		
Degree of Expansion Classification					
2	Linear Shrinkage (%) (Attimeyer, 1956)	<5	Non – Critical	0.30%	Non critical
		5 – 8	Marginal		
		>8	Critical		
3	Free Swell (%) (Dawson, 1956)	<50	Low	10%	Low
		>50	High		

Journal of Applied Geographical Studies
ISSN 2958-7433 (online)
Vol.1, Issue No.1, pp 15–30, 2021 www.carijournals.org

Table 4: Results of Physico-Mechanical Tests / standards used in the interpretation

Parameters	Test Results	Standard	Remark/Interpretation
Specific Gravity	2.58	<2.60	Good
Water absorption (%)	1.90	<3.0	Good
ACV (%)	23.50	<30	Good
LAAV (%)	42.70	< 45	Good
AIV (%)	29.40	<30	Good

4.2 Discussion

4.2.1 Assessment of suitability based on geotechnical properties (Tables 2 and 3)

The results from the study area, for Atterberg Limit, Free Swell and Linear Shrinkage Limit indicate that due to the values gotten, it has low swelling potential (Dawson, 1956), it is non-plastic (Ola, 1981), and the favourable degree of expansion (Attimeyer, 1956) makes the marl deposit of Afikpo good material for highyway pavement. Compared to natural gravels, in a study of the suitability of gravel deposits from Ihiagwa, Okeke and Agbasoga (2001) noted that the smooth texture of the gravels decrease bonding of the aggregates with cement in the concrete and is also responsible for the lower compressive strength of concrete made from Ihiagwa gravel aggregates.

4.2.2 Assessment of suitability based on physic-mechanical properties (Table 4)

The result of the physico-mechanical properties of marl samples from the study area shows that values are within the acceptable limits for highway pavement aggregates, building stones and facing/decoration stones respectively (BS 882, 1973; FMW 1997). From this result, the water absorption and aggregate crushing values are within the acceptable limits for highway pavement aggregates, building stones and facing/decoration stones, since their values are less than 3% and 30% respectively (BS 882, 1973; FMW 1997).

Furthermore, the Los Angeles abrasion value from General Specification, FMW 1997 Nigeria and BS 882, 1973 suggested also that Los Angeles Abrasion should be equal to or less than 45% for road base material in lightly trafficked road. The aggregate crushing value of aggregate is a measure of the resistance of the aggregates to crushing under a gradually applied compressive load while Los Angeles abrasion value is a measure of the resistance of the aggregates to surface wear by abrasion (the lower the value, the greater the resistant) (Okeke & Agbasoga, 2001). The water absorption of the aggregates controls the amount of binder required in surface design (high water absorption value will need more binder materials after the ingredients have been mixed). According to Akpokodje (1992) and Okeke et al., (2011) aggregates that satisfy the requirements for highway pavement aggregates also satisfy the requirements for concrete aggregates provided that they do not possess deleterious silica minerals (opal and chalcedony) that will force deleterious alkali-aggregates reaction. Aggregates derived from calcareous rocks like limestone and marl do not possess such minerals. Such aggregates (natural gravels and crushed sandstone) generally have uniaxial compressive strength of above 20N per mm^2, whereas the minimum needed for concrete made from any aggregate is 15N per mm^2 (CP 110, 1972).

The specific gravity of the marl sample is 2.58. These values when compared with standard suggest that the marl possess the required specific gravity value required for highway aggregates. According to Akpokodje (1992), the specific gravity of aggregates is an important property that is required for the design of concrete and bituminous mixes. The specific gravity of a solid is the ratio of its mass to that of an equal volume of distilled water at a specified temperature. The higher the specific gravity, the denser the rock and stronger is the aggregate.

5.0 Conclusion

The Marl deposit under study belong to the Ezeaku Formation. Field observations identified sandstone ridges trending NE-SW with subordinate marl deposits exposed along the Amasiri-Akpoha axis. Geotechnical tests confirmed that the rock has low swelling potential, non-critical linear shrinkage and low degree of expansion. The physico-mechanical strength characteristics also are within the acceptable limits for highway pavement aggregates. The Marl deposit in Afikpo Area, Southeastern Nigeria is therefore a good rock to be used as aggregate for highway pavement.

The following recommendations are therefore made:

i. Aggregates derived from marl deposit in Afikpo area, Southeastern Nigeria, are good materials to be used as aggregates for both concretes and highway pavements
ii. Further studies should be conducted to determine the quantity/reserve of the deposit in Afikpo area and other areas with similar geology in Southeastern Nigeria.

Acknowledgements

The authors are grateful to the laboratory staff of Institute of Erosion Studies, Federal University of Technology Owerri, for their assistance in Laboratory analysis of rock samples. They are also grateful to the anonymous reviewers.

References

Akpokodje, F.G. 1992.Properties of Some Nigerian rock aggregates And concrete .J. Of Min. and Geol. 28. (3) pp-185-190.

Attimeyer, W.T. (1956). Discussion of Engineering Properties of Expansive soils by Hoetz, W.G And Gibbs, H.G (1956) Trans. ASCE- vol.121, 641-677.

Bell, F.C. (2004). Engineering Geology and Construction. Spon Press, London.

Bell, F.G. (2007). Engineering Geology. 2nd Edition. Elsevier, Amsterdam.

Benkhelil, J. (1986). Structure and geodynamic evolution of the Intracontinental Benue Trough (Nigeria), Ph.D Thesis, University of Nice 202p. Pub. El (Nig.) Ltd.

Braithwaite, C. (2005). Carbonate Sediments and Rocks. Whitles Publishing, Dunbeath, Scotland.

British Standards (BS) 1137 (1975) Methods of Testing Soils for Civil Engineering Purposes. British Standards Institution, London.

British Standards (BS) 882. (1973). Specifications for aggregates from natural sources for concrete and roadstones, British Standard Institution, London.

Burke, K.C. Dessavague, TFJ. And Whiteman A.T (1972). Geologic History of the Benue Trough and adjacent areas in African Geology (TFJ Dessauvague A.T. Whiteman Ibadan University Press, Ibadan; 181-205)

Clultterbuck, P.J., Ingles O.G., and Talbot C.J., (1982). Rocks as Construction Material. Association of Geoscientists for International Development (AGID), Bangkok, Thailand.

Code of Practice (CP) 110 (1972). Structural Use of Concrete Part I. British Standard Institution, London.

Cripps, J.C., Culshaw, M.G., Coulthard, J.M. and Henshaw, S. (1992). Engineering Geology of Weak Rocks. Engineering Geology, Special Publication, No. 8. A.A. Balkema, Rutterdam.

Dawson, R.F., (1956). Discussion of engineering properties of expensive soil by Holts. W.G and Gibb, H.J. ASCE Transaction 121:644-666.

Farmar, F.W. (1983). Engineering Behaviour of Rocks. Chapman and Hall, London.

Federal Ministry of Works (FMW) (1997). Specification Limits for Materials (Roads and Bridges) Federal Ministry of Works, Abuja, Nigeria.

Goodman, R.E. (1993). Engineering Geology: Rock in Engineering Construction. John Wiley, New York.

Hardcastle, J.H., (2003) Evaluation and treatment of expensive soils in US 95 Owhee County, Idaho (Prepared for Idaho Department of Transportation, National Institute for Advanced Transportation Technology University of Idaho).

Heidema, P.B., (1957). The bar-linear shrinkage test and its practical importance as an identifier of soils Proc., 4th International Conference on Soil Mechanics and Foundation Engineering, London: 44-49

Igwe, E.O, and Okoro, A.U. (2016) / Field and lithostratigraphic studies of the Eze-Aku Group in the Afikpo Synclinorium, Southern Benue Trough, Nigeria. Journal of African Earth Sciences: 34(1): 119-138.

James, P.M. (1993). Engineering Problems Associated with some Unusual Weathered Processes in Limestones. In: Engineering Geology, Hydrogeology and Environmental Geology, Vol. 2. McNally, G., Knight, M. and Smith, R. (Eds). Environmental Engineering and Hydrogeology Special Group. Geological Society of Australia. Butterfly Books, Springwood, New South wales, Australia: 58-62.

Krynine, D.P. and Judd, W.R. (1957). Principles of Engineering Geology and Geotechnics. McGraw-Hill Book Company, New York.

Murat, R.C. (1972). Stratigraphy and Palaeogeography of the Cretaceaous and Lower Tertiary in the Southern Nigeria. In: Dessauvague, T.F.G. and Whiteman, A.J. (Eds.), African Geology. Ibadan University Press: 251-266.

Nwachukwu, S.O., (1972). The tectonic evolution of the Southern portion of the Benue Trough, Nigeria. Geological Magazine, 109:411-419.

Nwajide, C. S., (1990). Cretaceous sedimentation and paleogeography of the of the Central Benue Trough, In C. O. Ofoegbu, (ed.), The Benue Trough: Structure and Evolution, Wiesbaden Germany.

O'Flaharty, C.A., (1974). Highways, Vol. 2. Highway Engineering, 2nd Edition Edward Arnolod, London.

Okeke, O.C and Agbasoga, J. (2001). Evaluation of suitability Ihiagwa Gravel Deposit as aggregates for concrete and highway Pavement. Journal of Mining and Geology, 37 (1): 77-84.

Okeke, O.C., Israel, H.O., Enwelu, C., and Ekere, J.T., (2011). Identification and engineering characterization of some basement rock samples from Oban Masif, Southeastern Nigeria. *Journal of Research in Engineering*, 8(2):119-126.

Ola, S.A. (1981). Mineralogical Properties Of some Nigerian Residual soils in Relation with Building Problems. Engineering Geology, 15: 1-13.

Olade, M.A (1975) Evolution of Benue Trough (Aulacogen); Tectonic model Geomagazine 12(5) 575 – 583.

Reyment, R.A (1965) Aspects of the Geology of Nigeria. University Of Ibadan press, Ibadan, Nigeria, 149p.

Singh, A. (1992). Modern Geotechnical Engineering. 3rd Edition. CBS Publishers & Distributors, New Delhi, India.

Umeji, O.P. (2010). Palynostratigraphy, Sequence stratigraphy and Palaeoecology of the Campanian-Maastrichtian Nkporo Group in Afikpo – 4 well, Afikpo Syncline, Southeastern, Nigeria. Journal of Mining and Geology, 46(1): 93-112.

US Bureau of Reclamation (USBR) (1963). Earth Manual. US Government Printing Office, Washington D.C.

Whiteman, A.T (1982). Nigeria: Its Petroleum Geology Resources and Potential. Granora and Thutrua London.