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Original Article

Petrography and Geotechnical Evaluation of Syenite Aggregate Around Igarra, Southwestern Nigeria, for Pavement Construction

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Abstract *- Ten rock outcrop samples were obtained in an attempt to determine the relationship between the petrography and the geotechnical properties of the Syenite around Igarra, Southwestern Nigeria, using thin-section petrography and geotechnical analyses of rock aggregates, respectively. The result of the modal analysis shows the average mineral composition in the sample as 9.9 % plagioclase, 7.6 % quartz, 18.6 % biotite, 11.6 % hornblende, 12.2 % muscovite, 39.5 % microcline, and 0.6 % opaque. The rock samples are mostly holocrystalline of equi-granular fine-medium-grained crystals, with a minor presence of interlocking texture with euhedral to subhedral grains and perthite with interlocking euhedral to subhedral grains in some samples. All the aggregates are strong and durable for pavement construction, as they largely meet the low acceptance values of >2.55%, < 1%, <35%, <35%, and <35% required for specific gravity, water absorption capacity, aggregate impact values, aggregate crushing values, and Los Angeles Abrasion values respectively. However, acceptance values of <30 % for the flakiness index and <30% elongation index were not attained. It was observed that mica contents have a negative correlation with strength.*

Keywords *- Aggregates, Geotechnical, Pavements, Petrography, Syenite.*

1. Introduction

The Syenites are holo-leucocratic to leucocratic intermediate igneous rock that forms from the cooling of silica-saturated to silica under-saturated magma from the crust or mantle [1]. It occurs in a variety of magmatic terrains, as well as in metamorphic rocks. Syenites have distinctive petrography, geochemistry and geotechnical features, which are important in their differentiation characterization. Syenites are economically important in mining and processing industries because they can serve as hosts to gemstones and ore minerals [3].

They have a slightly different composition from granite since they are deficient in quartz or may occur in relatively small concentrations. Syenite is composed of alkali feldspar and ferromagnesian minerals [4]. The selection of syenite aggregate for pavement construction is influenced by its physical, mechanical and mineralogical composition. Ugbe [6] noted that aggregates with higher specific gravity and quartz contents are most suitable for construction purposes. This finding is in line with [7], who studied the mineralogical and geomorphological characteristics of aggregates of granite, diabase and limestone and noticed higher strength of granite under VSI crushing operation. According to [8], the understanding of aggregate strength used in construction is vital in order to prevent continuous structural failure noticeable around the World. Ademila [8] also noted that the variations in rock's properties are contributed by a number of factors, such as mineral composition and texture. It has been observed that mineralogical and textural diversity have a significant influence on the rock's mechanical characteristics. Therefore, for any aggregate to be used for pavement construction, it must resist crushing and abrasion. It also has to be durable in the prevailing environmental conditions. The current challenges confronting the Nigerian economy have necessitated searching for locally available materials for domestic and industrial applications [10]. Syenite is quite abundant in the study area, although relatively rare when compared to other crystalline rocks [11, 12]. However, granite aggregates are preferred even when they have to be hauled from a great distance for road construction. The cost of haulage has become so prohibitive considering the high inflation rate presently being experienced in Nigeria. This has significantly increased the cost of road construction, thereby resulting in serious infrastructural deficits within the area.

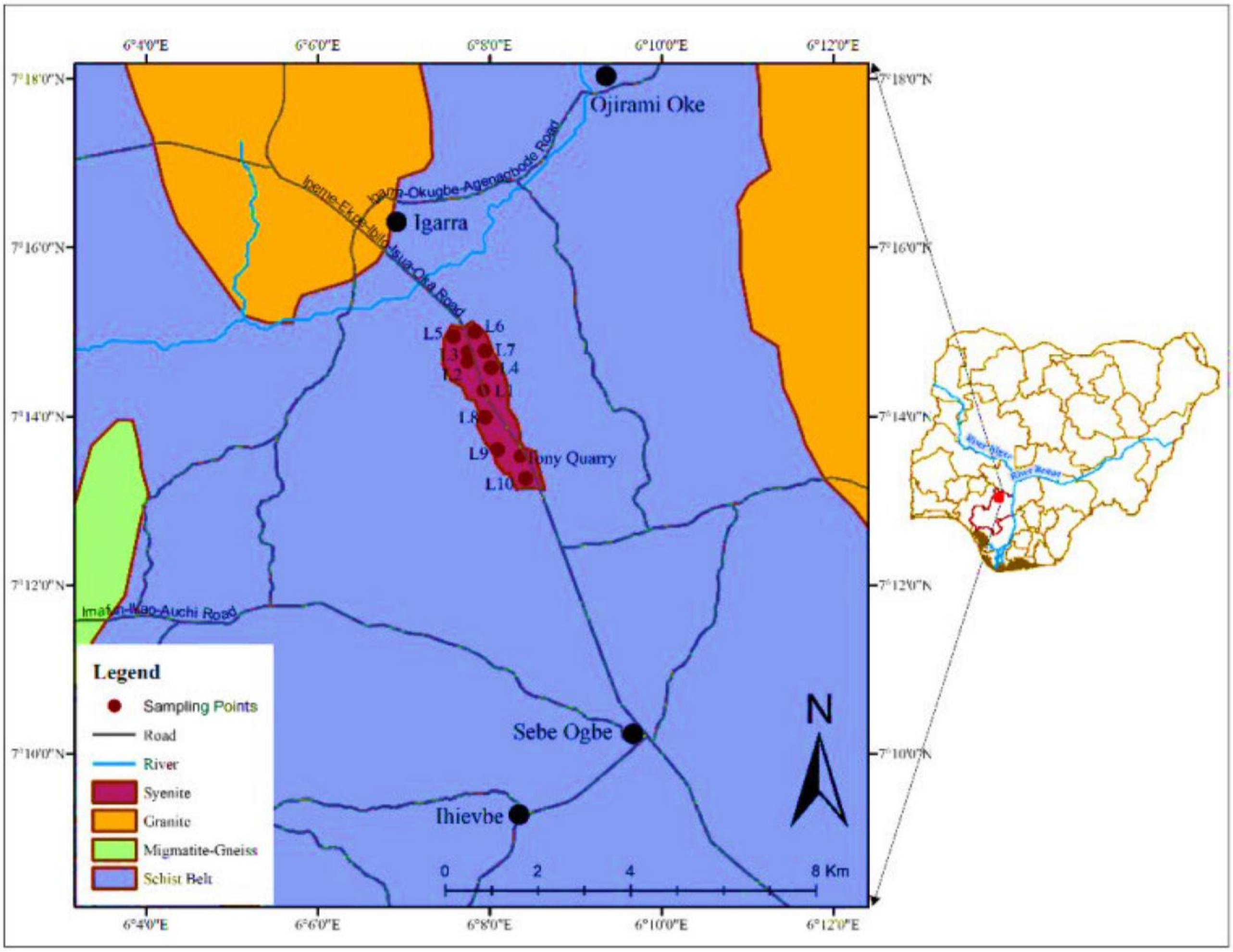

Fig. 1 Geological/sample location map of igarra and environs

The aim of this study, therefore, is to evaluate the petrography and geotechnical characteristics of the syenite aggregate to ascertain their suitability for pavement construction because it will, in no doubt, drastically reduce the cost of construction of roads and facilitate rapid infrastructural development within the study area.

1.1. Description of Location and Geology of the Study Area

The study area (Figure 1) is situated in Igarra, southwestern Nigeria. It is located between latitudes 07°13' 31.4" to 07° 15' 0.6" N and longitudes 06° 07' 44.4" to 006° 08' 27.6" E. It is a section of the basement complex towards the southwest, which is separated into three primary groups: Biotite hornblende and Migmatite gneiss, low grade (schists, calc-gneiss, marble, metaconglomerates and quartzites) [12].

Minor rock types include syn- to late tectonic porphyrite biotite-hornblende granodiorites, adamellites, charnokites gabbros, unmetamorphosed dolerite, pegmatite, aplite, and syenite dykes, and unmetamorphosed dolerite, pegmatite, aplite, and syenite dykes. Syenite is one of the youngest Precambrian rock groups in the Nigerian Basement Complex. They are syn-to-late tectonic, with the majority of their activities occurring during the Pan-Africa Orogeny's waning phase.

2. Materials and Methods

Ten syenite outcrop samples were obtained from the study area. Samples were cut and polished for thin sections using the Logitech thin-section rock-cutting machine (model GT51) for onward petrographic and mineralogical studies. The rock slides were viewed under the Olympus Triocular polarizing microscope, with a digital camera attached, to capture the rock slides' photomicrographs obtained under cross- and plane-polarized lights. A statistical test (t-test) was carried out to determine the significance of the variables.

The point count method [14] was used to ascertain the modal composition of the syenite. At the same time, textural parameters, including grain size, grain shape, packing density and the degree of interlocking of grains, were determined by visual inspection of thin sections observed under the microscope.

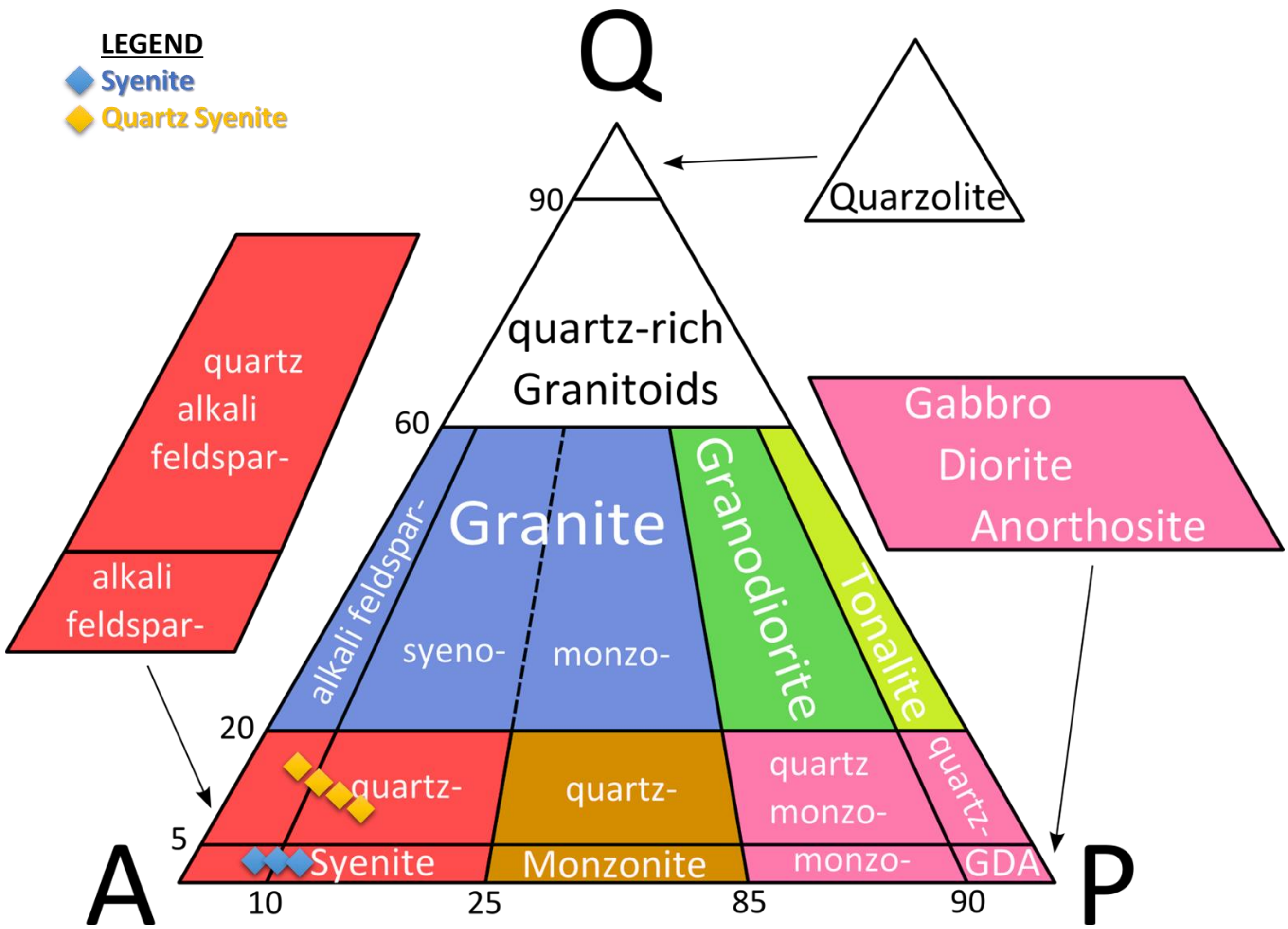

Fig. 2 Modal plots of Igarra syenite in IUGS-recommended Q-A-P diagram (Q: quartz; A: alkaline feldspar; P: plagioclase feldspar). Adapted from Streckeisen [17]

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The syenite rock samples obtained from quarries were crushed into aggregates in the laboratory and after that the aggregates were subjected to geotechnical analyses in accordance with the American Society for Testing and Materials (ASTM C131 and ASTM C127), the British Standard Institution (BSI 812) and the Federal Ministry of Works Standard (FMW) [15] in an attempt to determine the Los Angeles abrasion value (LAAV), Specific gravity (SG), Water absorption capacity (WAC), Aggregate Crushing value (ACV), Aggregate Impact value (AIV), Flakiness Index (FI), and Elongation-Index (EI).

3. Results and Discussion

The modal compositions of the syenite samples are indicated in Table 1. The plot of the modal composition on Quartz (Q)-Alkaline feldspar (A)-Plagioclase feldspar (P) ternary diagram reveals the rock samples as syenite while few samples plotted as quartz syenite (Figure 2). Representative photomicrographs (both in cross- and plane-polarised lights for each sample) typical of the syenite rock samples are shown in Figure 3. The texture of the syenite rock samples ranged from fine to medium, with grain interactions that are fairly well-defined, indicating a low degree of weathering. The result of the modal analysis shows the average mineral composition in the sample as 9.9% plagioclase, 7.6% quartz, 18.6% biotite, 11.6% hornblende, 12.2% muscovite, 0.60% opaque, and 39.5 % microcline being the dominant mineral (Table 1).

Table 1. Modal compositions (in %) of syenites from igarra

[1]S #	[2]P	[3]Q	[4]M	[5]B	[6]H	[7]Mu	[8]O
S1	8	10	38	20	7	15	2
S2	8	12	45	20	3	12	
S3	10	10	40	22	8	10	
S4	5	10	37	20	12	15	1
S5	10	5	40	20	10	12	3
S6	12	5	40	20	13	10	
S7	15	5	35	15	20	10	
S8	8	7	40	17	13	15	
S9	15	5	40	17	11	12	
S10	8	7	40	15	19	11	
Av.	9.9	7.6	39.5	18.6	11.6	12.2	0.6

[1]**S#** (Sample code); [2]P (Plagioclase); [3]Q (Quartz); [4]M (Microcline); [5]B (Biotite); [6]H (Hornblende); [7]Mu (Muscovite); [8]O (Opaques); Av: Average mineralogical composition.

3.1. Results of Petrographic Studies

In thin sections, the rock samples are mostly holocrystalline of equi-granular fine-medium grained crystals, with a minor presence of interlocking texture with euhedral to subhedral grains, as well as perthite with interlocking euhedral to subhedral grains (Figure 3).

3.2 Physico-Mechanical Properties

The result of the physicomechanical properties of the aggregates is shown in (Table 2). High values were recorded for flakiness and elongation indices; the flakiness index ranges between 38 and 41.1%, while the elongation index varies between 37.9 and 42.1% (Figure 4). These values are very high, above the acceptance value of 30 % recommended by FMW [15].

These high values obtained for flakiness and elongation indices can be largely attributed to the modification in the rock's physical properties brought about by the Pan-African Orogeny associated with the syenite of the Southwestern Nigeria Basement Complex. Figure 5 shows the alignment of elongated minerals, which is typical of foliation, which confirms the report of [18]. This may be responsible for the shape indices that are above the acceptable limit of 30%, as recommended by FMW [21].

The SG value obtained for syenite aggregates ranges between 2.73 and 2.88 (Figure 5); this is within the acceptance value of >2.55. It has been noted that rock aggregates with a specific gravity greater than 2.55 are suitable for heavy construction work [20].

The syenite aggregates have low water absorption capacity, which ranges between 0.1 and 0.3% (Table 2), and it, therefore, falls within the acceptance value of < 1 % recommended by [21], which established the aggregates as suitable for pavement construction. With the low water absorption capacity value and high specific gravity, the syenite aggregates are suitable for heavy construction work, consistent with the work of [6].

The strength parameters of rock aggregates, such as aggregate impact value (AIV), aggregate crushing value (ACV), and Los Angeles abrasion value (LAAV), are used to evaluate the suitability of the aggregates for use in pavement construction. The AIV ranges from 11.6 to 14.5%. These values fall within the permissible limit of < 35% recommended by [23]. Such low AIV implied stronger aggregates that are good for road construction [24]. The ACV varies from 23.2 to 25.4 % (Table 2); these values are within the permissible limit of < 35 % suggested by [26].

The syenite aggregates are, therefore, suitable for pavement construction, and these results are consistent with those of earlier work [8]. LAAV ranges between 21 and 24 %; these values are below the acceptance value of 35% recommended by [27]. The low values of LAAV also indicate the suitability of syenites aggregates for highway pavement construction. Figure 5 shows correlation regression for the various parameters.

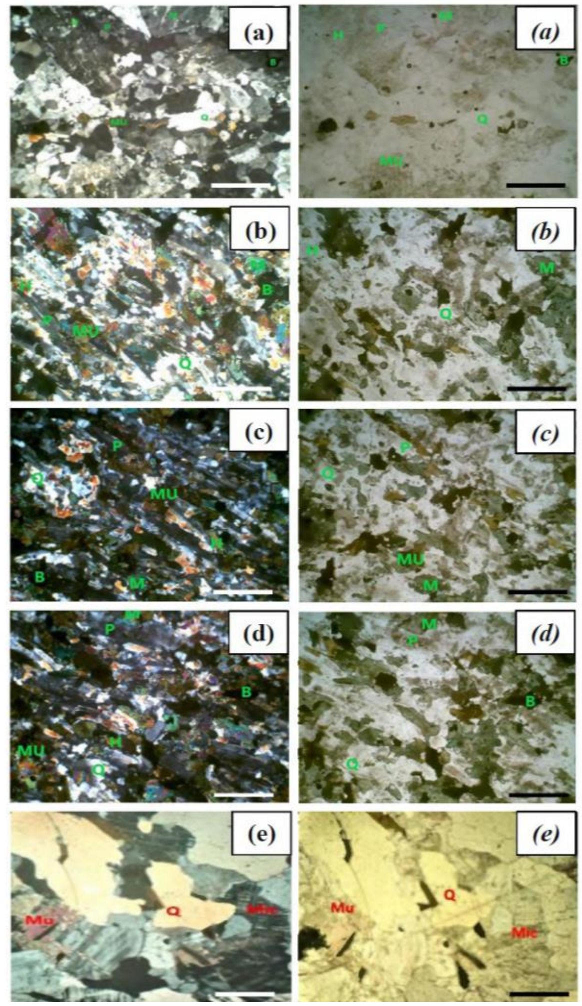

Fig. 3 Photomicrographs of selected Syenite samples from Igarra indicating various mineralogical compositions. Scale bar = 2mm. Note: photomicrographs taken in cross- and plane-polarised lights are labelled in normal and italic fonts, respectively. Q = Quartz; M = Microcline; MU = Muscovite; B = Biotite; P = Plagioclase feldspar

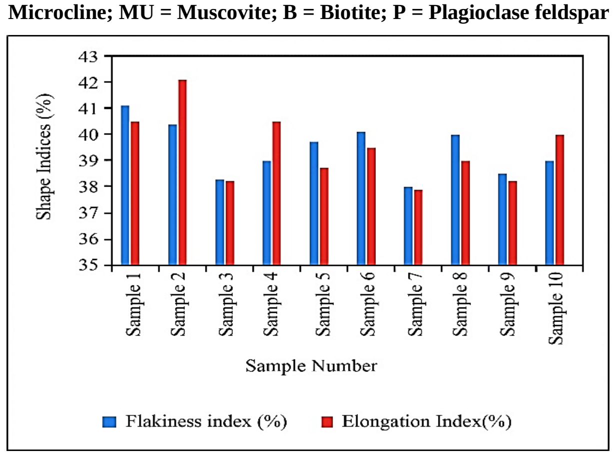

Fig. 4 Shape indices of the syenite aggregate from igarra

Table 2. Geotechnical properties of syenite aggregates around igarra

S #	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	*A. V.	Source
[1]AIV (%)	11.6	12.3	12.5	12.8	13	13.5	13.9	13.9	14.2	14.5	<35%	BSI 812:112 [23]
[2]ACV (%)	23.2	23.5	23.9	24	24.4	24.8	24.8	25	25	25.4	35%	BSI 812:110 [26]
[3]SG	2.73	2.75	2.79	2.77	2.82	2.75	2.85	2.82	2.85	2.88	>2.55	ASTM C127 [20]
[4]WAC (%)	0.3	0.25	0.2	0.2	0.1	0.25	0.1	0.2	0.2	0.1	<2%	ASTM C127 [21]
[5]LAAV (%)	21	21.5	22.1	22.3	23.1	23.5	23.8	23.8	24	24	<35%	ASTM C131 [27]
[6]FI (%)	41.1	40.4	38.3	39	39.7	40.1	38	40	38.5	39	<30%	FMW [15]
[7]EI (%)	40.5	42.1	38.2	40.5	38.7	39.5	37.9	39	38.2	40	<30%	FMW [15]

[1]AIV (Aggregate Impact Value); [2]ACV (Aggregate Crushing Value); [3]SG (Specific Gravity); [4]WAC (Water Absorption Capacity); [5]LAAV (Los Angeles Abrasion Value); [6]FI (Flakiness Index); [7]EI (Elongation Index); *A.V. (Acceptance Values); S # (Sample code).

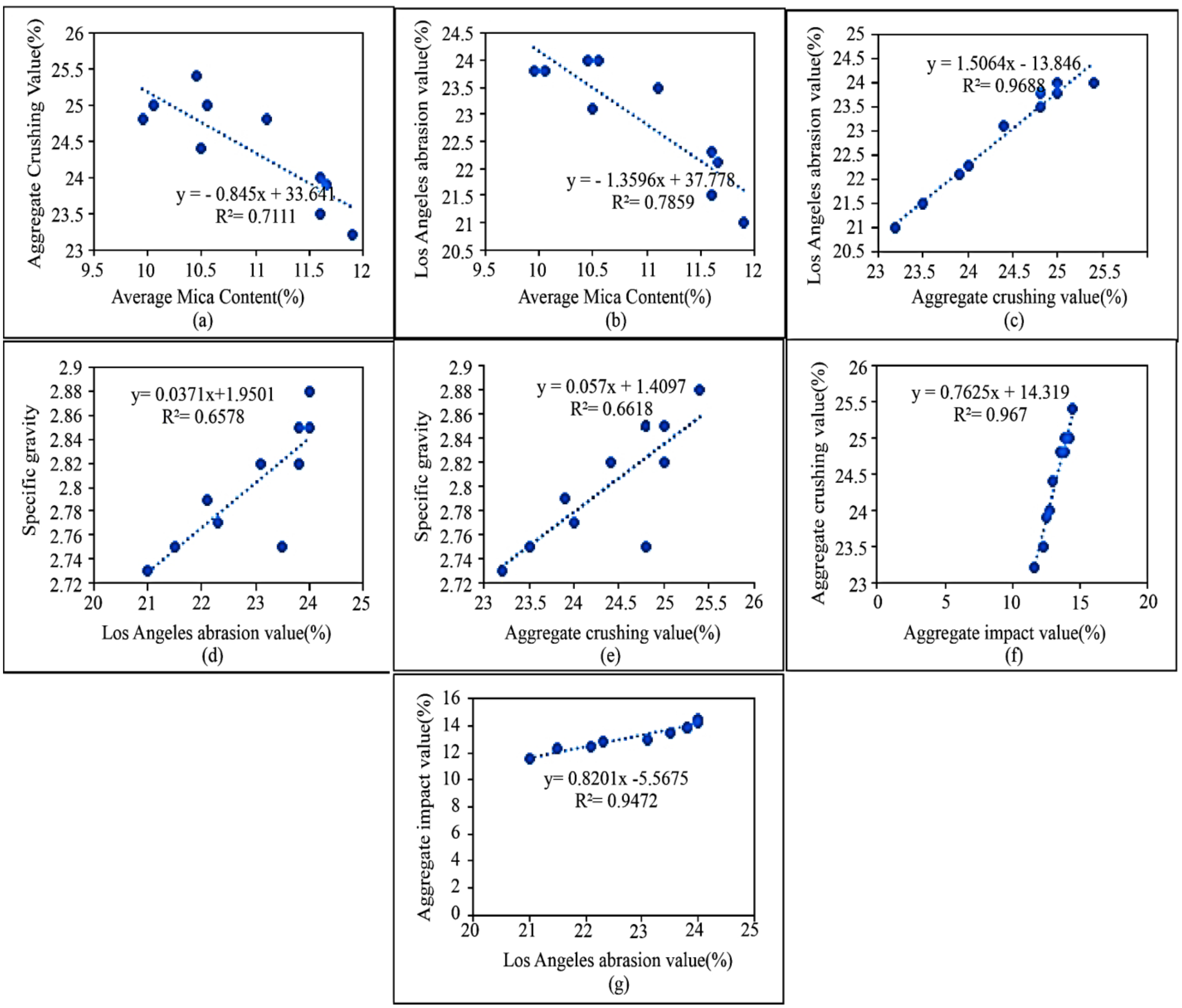

Fig. 5 Scattered diagram with regression line correlating: (a) Average mica content and ACV; (b) Average mica content and LAAV; (c) LAAV and ACV; (d)SG and LAAV; (e) SG and ACV; (f) ACV and AIV; and (g) LAAV and AIV

Table 3. t- and p-values of variables

Variables	t-values	p-values	Remark
ACV vs Quartz	-3.545	0.008	Significant
AIV vs Quartz	-2.998	0.017	Significant
LAAV vs Quartz	-4.512	0.002	Significant
AIV vs AMC	-2.764	0.025	Significant
LAAV vs AMC	-2.740	0.025	Significant
SG vs WAC	-4.450	0.002	Significant
ACV vs SG	3.957	0.004	Significant
AIV vs SG	4.506	0.002	Significant
LAAV vs SG	3.921	0.004	Significant
ACV vs AMC	-.2.259	0.054	Not significant
ACV vs WAC	-2.275	0.052	Not significant
AIV vs WAC	-2.280	0.052	Not significant

Statistical significance was observed across the various variables tested. The p-values, less than the alpha value ($p = 0.05$), were obtained across the variables tested (Table 3). However, variables such as ACV vs AMC, ACV vs WAC and AIV vs WAC were the few exceptions recorded with their p-value exceeding the alpha value ($p = 0.050$). Hence, they are considered statistically not significant.

4. Conclusion

The following conclusions are made after evaluating the suitability of the syenite samples using petrography and geotechnical characteristics. Using an internationally acceptable igneous rock classification diagram (IUGS QAP diagram), the syenite samples around Igarra were plotted as syenite and quartz syenite.

The syenite aggregates are adjudged suitable in accordance with BSI, ASTM and FMW standards. The values of WAC and SG are within the acceptable value for their use as pavement construction materials. Increase in mica content lowers the strength of the aggregates since the mica content correlates negatively with the strength properties of aggregates.

The findings in this work will guide the selection and use of syenite found in other terrains for better and more durable pavement construction.

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