Usability of Crystalline Basement Rocks as Construction Materials: Case Study of Ajaokuta Area, Kogi State, Nigeria

Adiotomre, E. E.

Abstract— Five crystalline basement rocks (porphyritic granite, migmatite, quartzite, granite gneiss and mica schist) located in the Ajaokuta area are investigated to evaluate their mechanical strength, physical and petrographic characteristics. Results illustrate that the migmatite has the highest uniaxial compressive strength (12.77N/mm2), and the micaceous quartzite has the minimum uniaxial compressive strength (2.85N/mm2). Other rocks in the area such as porphyritic granite, granite gneiss and mica schist have uniaxial compressive strength of 3.11N/mm2, 5.68 N/mm2 and 3.13N/mm2 respectively. There is a reasonable correlation between the mechanical and physical strengths parameters. Specifically, an increase in mechanical strength of the analysed rocks is analogous to an increase in specific gravity and dry density, and a decrease in porosity. Furthermore, rocks that are high in quartz and mica content, anisotropic, coarse-grained, and with micro-structural cracks and poorly interlocked mineral grains are characterized by lower mechanical strength values. The results of the study illustrate that the migmatite, quartzite and the granite gneiss are the most suitable for use as construction materials, and the porphyritic granite and mica schist are least suited.

Index Terms— Ajaokuta, Construction materials, Nigeria, Uniaxial compressive strength, Strength parameters.

◆

1 Introduction

Crystalline basement rocks are used widely in a variety of applications including road construction, buildings, pavements, dam fills and a range of other uses. However, the effective use of crystalline basement rocks for construction purposes depends on a range of factors. Some of these factors include mechanical strength, physical strength index (e.g. porosity, dry density and specific gravity) and petrographic characteristics (e.g. mineral grain size, mineral interlocking relationship, quartz, feldspar and mica content) [1, 2, 3, 4, 5, 6, 7, 8, 9]. The cost of shipping quarried rock fragments or chips for use in construction sites is exorbitant particularly if these materials are ship from distant localities. Therefore, the nearness to the source of these materials is an important consideration in the planning and management of related engineering projects. Furthermore, the Federal Government of Nigeria recently indicated an interest to rejuvenate the Ajaokuta Steel Company established over 30 years ago and later abandoned before the project could be fully completed due mainly to international politics and to a lesser extent mismanagement. Certainly, this will entails much construction works that may include resurfacing or construction of new link roads and refurbishing and/ or development of dilapidated buildings. It is, therefore, imperative to evaluate the potential of the crystalline basement outcrops that are extensively distributed in the Ajaokuta area for use as construction materials.

The Ajaokuta area lies between latitude 7o20'Nand 7o35' N and Longitude 6o30'E and 6o44', and is within the south-western Basement Complex of Nigeria (Fig. 1). The Nigerian Basement Complex consists of the migmatite-gneiss complexes, the older metasediments, the younger metasediments, the older granites and, the younger granite complexes and volcanic rocks [10, 11, 12, 13]. The Migmatite-Gneiss Complex consists of gneisses, amphibolites, migmatite and metavolcanics. The older metasediments include rocks such as quartzite, calcareous rocks (e.g. marble) and relics of highly altered clayey sediments and igneous rocks. The Younger Metasediments consists of quartz-biotite-muscovite schist and coarse-grained feldspar-bearing micaceous schist although ferruginous quartzite and talc schist may also occur. The older granites occur as large circular masses within the Schist and the Migmatite-Gneiss Complexes. The Younger Granite Complexes formed a distinctive group of intrusive and volcanic rocks bound by ring dykes or ring faults. Locally the rock types located in the field are quartzite, porphyritic granite, migmatite, mica schist, biotite gneiss.

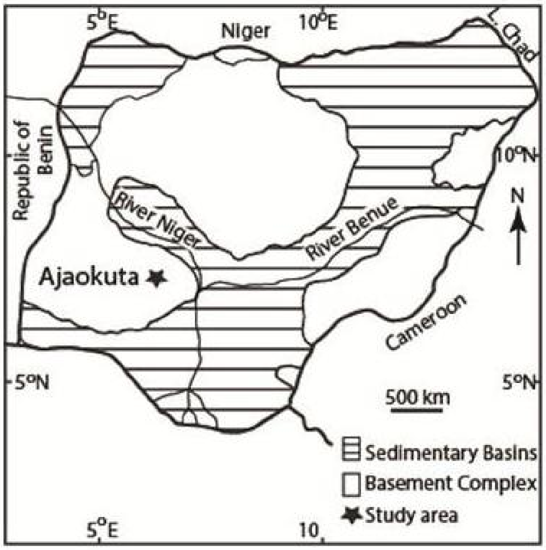

Fig. 1. Schematic geologic map of Nigeria showing the study area; adapted from [14].

2 Materials and Methods

The mechanical strength of the rocks located in the study area is evaluated using the Point load testing machine in the Laboratory of Fugro Nigeria Limited. The testing procedure adopted is in line with the method used in previous studies [e.g. 15, 16, 6] and conforms to the standard of [17]. As part of the testing process, load is applied axially and continuously at a nominal rate of 0.2N/mm2 to 0.4N/mm2 until the failure of the rock sample occurs. The point load strength evaluation method is an indirect compressive strength testing technique. Hence in this study, obtained point load index is converted to the uniaxial compressive strength of the rocks following the method of conversion proposed by [18] as follows:

$\sigma c = KIs$

Where,

σc = uniaxial compressive strength

Is = point load index

K = conversion factor obtained from [18] size correlation graph for index-to-strength conversion.

Routine laboratory methods are employed to determine the physical strength parameters of the rocks and conform to the procedure adopted by [6]. Thin sections are prepared from the rock samples and used to illustrate the petrographic characteristics that relate to the mechanical strength of the rocks.

3 Results and Discussion

Results of mechanical strength evaluation of the crystalline basement rocks illustrate that the migmatite has the highest uniaxial compressive strength, and the porphyritic granite is characterized by the lowest uniaxial compressive strength (Table 1; Fig. 2). In general the average uniaxial compressive strength of the rocks in a decreasing order is 12.77N/mm2 (migmatite), 8.49N/mm2 (quartzite), 5.68N/mm2 (granite gneiss), 3.13N/mm2 (mica schist) and 3.11N/mm2 (porphyritic granite). The average specific gravity obtained for the studied rocks decreases from a maximum of 2.725 in samples of the quartzite to a minimum value of 2.517 in the migmatite (Table 1; Fig. 2). Intermediate values of specific gravity characterized samples of porphyritic granite (2.636), granite gneiss (2.635) and mica schist (2.544). Previous study indicates that compressive strength of crystalline rocks increases as the specific gravity increases [e.g. 7]. The studied rocks with the exception of migmatite show increase in uniaxial compressive strength as specific gravity increases (Table 1; Fig. 2). Migmatite has the highest uniaxial compressive strength and also has the lowest specific gravity. The well interlocked mineral grains and low-moderate (10-20%) anisotropy of the migmatite enhances its compressive strength (Fig. 3a) [e.g. 19].

As indicated above, quartzite is also high in compressive strength, and this may be related to the high-quartz content (>94%) of the rock coupled with the fine-grained texture and well interlocked mineral grains. In previous studies, grain size has been shown to impact the properties of rocks and also intrinsically influence their engineering strength [e.g. 1, 20, 7, 19]. The amount of quartz in rocks has also been indicated to enhance their engineering strength [e.g. 2, 4, 7]. According to these workers, anhedral quartz grains can occupy interspaces between mineral grains reducing the porosity and ultimately enhanced the specific gravity and compressive strength of the rocks. Evaluated porosity of the rocks ranges from a minimum value of 0.11% (granite gneiss) to a maximum value of 0.94% (mica schist) (Fig. 2).

Table 1. Strength parameters of the rock units

Rock Units	Dry Density (g/cm^3)	Saturated Density (g/cm^3)	Uniaxial Compressive Strength (N/mm^2)	Porosity (%)	Specific Gravity
Porphyritic Granite	2.629	2.633	3.11	0.420	2.636
Quartzite	2.717	2.72	8.49	0.290	2.725
Migmatite	2.507	2.512	12.77	0.398	2.517
Granite Gneiss	2.632	2.633	5.68	0.110	2.635
Mica Schist	2.52	2.529	3.13	0.940	2.544

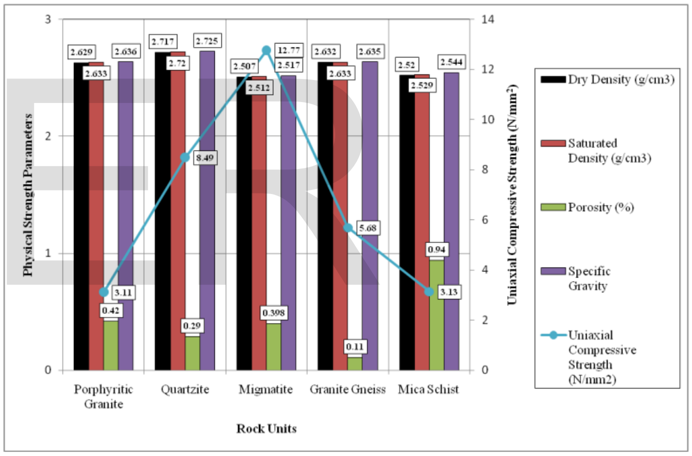

Fig. 2. Graphical representation of average values of strength parameters for the different rock units. Note the maximum uniaxial compressive strength that characterizes the migmatite.

It is also evident on Figure 2 that the evaluated saturated density of the studied rocks scarcely exceeds the dry density by more than 0.01g/cm^3, which corroborates the low porosity of the rocks. The low porosity that characterizes crystalline rocks has been reported in previous studies [e.g. 6, 21]. The recorded porosity of the rocks correlated reasonably with their densities, as dry density of the rocks increases, the porosity decreases (Table 1; Fig. 2). Porosity also decreases for rocks with higher uniaxial compressive strength which conforms to the findings of previous studies (Fig. 2) [e.g. 22, 8]. For instance, the granite gneiss that has a higher uniaxial compressive strength than the porphyritic granite and mica schist is characterized with a lower porosity. The comparatively low uniaxial compressive strength of the porphyritic granite may be due to the influence of the poorly interlocked and very coarse mineral grains of the rock that made it fail more readily. The mica schist in thin section shows preferred orientation of platy biotite and muscovite and micro-structural cracks (Fig. 3b). Although laths of mica and micro cracks also occurred in the porphyritic granite, granite gneiss and migmatite, they are more developed in the mica schist. The dimensional orientation of the mica introduced anisotropy in the rock fabric and coupled with the associated micro-structural cracks impact the compressive strength of the mica schist [e.g. 19]. The micro-structural cracks that are observed in these rocks may have developed as biotite expands when it is transformed to clay “pseudomorphs” [e.g. 23, 24].

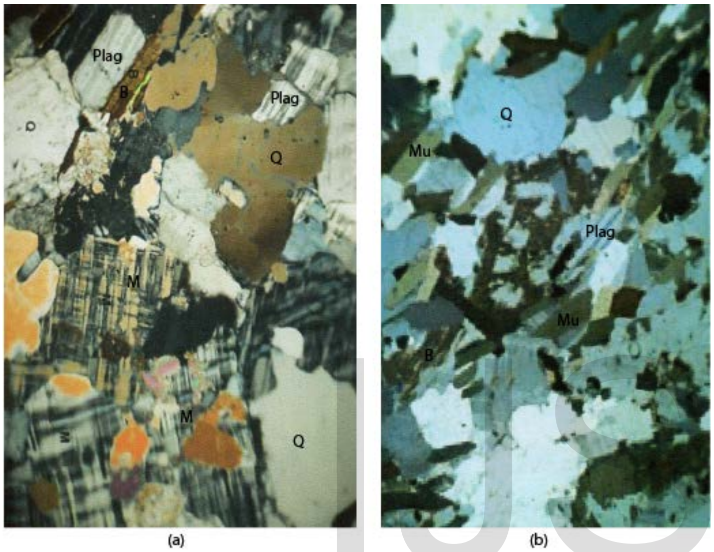

Fig. 2. Photomicrograph of (a) migmatite and (b) mica schist (with crossed polarised light. X40). Key: M = microcline; Plag = plagioclase; Q = quartz; Mu = muscovite; B = biotite.

4 Conclusion

Physical, mechanical and petrographic strength parameters of five crystalline basement rocks have been evaluated in this study. On the basis of the evaluated strength properties, the migmatite are mostly favoured for use as engineering construction materials since the rock has a high uniaxial compressive strength. In addition, the rock physical strength indexes such as specific gravity, dry density and porosity are also of reasonable magnitude and enhance the rock engineering strength. In thin rock sections, micro-structural cracks and anisotropy are moderately developed and as a result did not impact the rock engineering properties.

The use of granite gneiss and quartzite of the study area for construction works is also recommended. The uniaxial compressive strength of these rocks is reasonably good. The specific gravity of the granite gneiss and its low porosity are additional properties that favour its use as engineering construction material. The fine grained texture, high quartz content, high specific and dry density, low porosity and absence of gaps between mineral grains are some of the strength indexes that support the use of the quartzite for engineering construction works. The porphyritic granite has comparatively low uniaxial compressive strength probably as a result of the influence of the poorly interlocked and very coarse mineral grains of the rock that made it to fail readily. In thin section, the mica schist is composed of platy biotite and muscovite that shows dimensional orientation, and this coupled with the micro-structural cracks in the rock fabric strongly impact their use as construction materials. As a result of aforementioned deductions, the porphyritic granite and the mica schist of the study area are not highly favoured for use as construction materials. The engineering use of these rocks should be restricted to dam fills and gullies seal.

The results of the study demonstrates that the choice of crystalline rocks for engineering purposes should be based on all evaluated strength parameters so that frequent failures of structures in construction works is minimized or completely eliminated.

5 Acknowledgment

The author appreciates Fugro Engineering Nigeria Limited for providing the equipments used for the strength evaluation of the studied rocks.

References

[1] T.F. Onodera and H.M. Kumara, “Relation between texture and mechanical properties of crystalline rocks,” *Engineering Geology*, vol. 22, pp. 173–177, 1980.
[2] A. Shakoor and R.E. Bonelli, “Relationship between petrographic characteristics, engineering index properties and mechanical properties of selected sandstones,” *Engineering Geology*, vol. 28, pp. 55-71, 1991.
[3] E.G. Akpokodje, “Properties of some Nigeria rock aggregates,” *Journal of Mining and Geology*, vol. 23, no. 2, pp. 185-190, 1992.
[4] R. Ulusay, K. Türeli and M.H. Ider, “Prediction of engineering properties of selected litharenite sandstone from its petrographic characteristics using correlation and multivariate statistical techniques,” *Engineering Geology*, 37, 135-157, 1994.
[5] İrfan, T.Y., “Mineralogy, fabric properties and classification of weathered granites in Hong Kong,” *Engineering Geology*, vol. 29, pp. 5-35, 1996.
[6] E.E. Adiotomre, “On the petrography and physical strength indices in relation to the geomechanics of crystalline basement rocks in Ilora Province, Oyo NW, Nigeria,” *Bulletin Science Association of Nigeria*, vol. 21, pp. 77-78, 1997.
[7] A. Tuğrul and I.H. Zarif, “Correlation of mineralogical and textural characteristics with engineering properties of selected granitic rocks from Turkey,” *Engineering Geology*, vol. 51, pp. 303-317, 1999.
[8] N. Sabatakakis, G. Koukis, G. Tsiambaos, S. Papanakli, “Index properties and strength variation controlled by microstructure for sedimentary rocks,” *Engineering Geology*, vol. 97, pp. 80–90, 2008.
[9] N.O. Adebesi and G.O. Adeyemi, G.O, “Compressive strength properties of gneisses in south-western Nigeria,” *Quarterly Publication of Scientific Society of Mineral Wealth Technology Geotechnology*, vol. 15, no. 6, pp. 43-50, 2001.
[10] N.K. Grant, “Geochronology of Permian basement rocks from Ibadan, south-western Nigeria; Earth and Planetary,” *Science Letters*, vol. 10, pp. 29-38, 1970.
[11] M.A. Rahaman, “Review of Basement of south-western Nigeria”, *Geology of Nigeria*, C. Kogbe, ed., Lagos: Elizabethan Press, pp 41-58, 1976.
[12] N.G. Obaje, “Geology and mineral resources of Nigeria,” *Lectures Notes in Earth Sciences*, vol. 120, pp. 13-30, 2009.
[13] C. Obiora and V.U. Ukaegbu, “Petrology and geochemical characteristics of Precambrian granitic basement complex

rocks in the southernmost part of North-Central Nigeria," *Chinese Journal of Geochemistry*, vol. 28, no. 4, pp. 377-385, 2009.

[14] C.A. Kogbe, *Geology of Nigeria*. Lagos: Elizabethan Publishing Company, 1976.

[15] E. Broch and J.A. Franklin, "Point-load strength test," *International Journal of Rock Mechanics and Mineral Science*, vol. 9, pp. 669-697, 1972.

[16] S.C. Teme, "The engineering geological significance of the point-load index tests in rock material evaluation", *Nigeria Journal of Mining and Geology*, vol. 20, nos. 1 and 2, pp. 87-93, 1983.

[17] ISRM (International Society for Rock Mechanics), "Rock Characterization, Testing and Monitoring—ISRM Suggested Methods," E.T. Brown, ed., Oxford: Pergamon Press, pp. 211, 1981.

[18] Z.T. Bieniawski, "Point load in geotechnical practice," *Engineering Geology*, vol. 9, pp. 1-11, 1975.

[19] R. Prikryl, "Some microstructural aspects of strength variation in rock," *International Journal of Rock Mechanics and Mineral Science*, vol. 38, pp. 671–682, 2001.

[20] E.C. Robertson, "Experimental study of the strength of rocks," *Bulletin Geological Society of America*, vol. 66, pp. 1275–1314, 1995.

[21] S. Ceryan, S. Tudes, N. Ceryan, "Influence of weathering on the engineering properties of Harsit granitic rocks (NE Turkey)," *Bulletin of Engineering Geology and Environment*, vol. 67, no. 3, pp. 97-104, 2008.

[22] D.F. Howarth, "The effect of pre-existing microcavities on mechanical rock performance in sedimentary and crystalline rocks," *International Journal of Rock Mechanics and Mining Science and Geomechanics*, vol. 24, no. 3, pp. 223-233, 1987.

[23] E.B.A. Bisdom, G. Stoops, J. Delvigne, P. Curmi, He-J. Altemuller, "Micromorpholgy of weathering biotite and its secondary products," *Pedologie*, vol. 32, no. 2, pp. 225-252, 1982.

[24] J.R. Price and M.A. Velbel, "Rates of biotite weathering, and clay mineral transformation and neoformation, determined from watershed geochemical mass-balance methods for the Coweeta Hydrologic Laboratory, Southern Blue Ridge Mountains, North Carolina, USA," *Aquatic Geochemistry*, vol. 20, issue 2-3, pp 203-224, 2014.

- *Author name is currently pursuing masters degree program in electric power engineering in University, Country, PH-01123456789. E-mail: author_name@mail.com*