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The use of index tests to determine the mechanical properties of crushed aggregates from Precambrian basement complex rocks, Ado-Ekiti, SW Nigeria

Lekan Olatayo Afolagboye [a,*], Abel Ojo Talabi [a], Charles Adebayo Oyelami [b]

[a] Department of Geology, Ekiti State University, Ado-Ekiti, Nigeria
[b] Department of Geological Sciences, Osun State University, Osogbo, Nigeria

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ABSTRACT

This study assessed the possibility of using index tests to determine the mechanical properties of crushed aggregates. The aggregates used in this study were derived from major Precambrian basement rocks in Ado-Ekiti, Nigeria. Regression analyses were performed to determine the empirical relations that mechanical properties of the aggregates may have with the point load strength ($I_{S(50)}$), Schmidt rebound hammer value (SHR) and unconfined compressive strength (UCS) of the rocks. For all the data, strong correlation coefficients were found between $I_{S(50)}$, SHR, UCS, and mechanical properties of the aggregates. The regression analysis conducted on the different rocks separately showed that correlations coefficients obtained between the $I_{S(50),}$ SHR, UCS and mechanical properties of the aggregates were stronger than those of the grouped rocks. The T-test and F-test showed that the derived models were valid. This study has shown that the mechanical properties of the aggregates can be estimated from $I_{S(50)}$, SHR and USC but the influence of rock type on the relationships should be taken into consideration.

1. Introduction

About 52% of all construction aggregates are produced from crushed stone while the remaining 48% are from natural sand and gravel (Waltham, 2009). Aggregates are widely used in road construction, production of concrete, railway track ballast and filters. The suitability of aggregates in any civil engineering work is determined by evaluating its engineering behaviour in terms of its physical, mechanical and chemical properties. The engineering behaviour of aggregates have been found to depend on geological characteristics of the parent rocks from which they were derived (Waltham, 2009; Brattli, 1992; Goswami, 1984; Gérard and Michel, 1984). Modal composition, texture and particle shape have been shown to have influence on the mechanical properties of aggregates (Åkesson et al., 2001; Přikryl, 2001; Hartley, 1974; Lees and Kennedy, 1975; Kazi and Al-Mansour, 1980; Gérard and Michel, 1984).

Different laboratory tests are available to determine the mechanical properties of aggregates such as ability to withstand crushing, impact, and abrasive stresses in service and susceptibility to polishing. In most cases, British standard (BS EN 932, 2010; BS EN 933, 2010 and BS EN 1097, 2010) and the American Society for Testing and Material (ASTM C-131, 1989, ASTM C-535, 1989) give the standards for testing the aggregate properties. Aggregate impact value (AIV), aggregate crushing value (ACV) and ten percent fines (TFN) value are common tests used to determine aggregates strength. Aggregate abrasion value (AAV), Los Angeles abrasion value (LAAV) and polished stone value are used to test the durability of the aggregates. Carrying out these tests requires sophisticated laboratory techniques or procedures, specialized equipment and a great amount of time especially during sample preparation. Generally, a standard aggregate size of 10–14 mm is recommended and in most instances, this specified size of the aggregates may not be available, which often leads to testing of non-standard sized aggregates. As remarked by Onyejekwe et al. (2014): *"The use of correlations and empirical relationships offers a fast and cost effective means of predicting the value of a parameter based on the values of another, possibly more easily determined, parameters if the appropriate correlations are employed."* Therefore, the problems associated with these laboratory tests could be solved if it is possible to predict a reliable estimate of the mechanical behaviour of aggregates from the results of simpler tests.

* Corresponding author.
E-mail address: afotayour@hotmail.co.uk (L.O. Afolagboye).

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Table 1
Published correlations between the SHR, PLT, UCS and the aggregate strength properties for different types.

Relationship	Equations	R^2	Rock types	References
LAAV VS SHR	LAAV = −1.9 SHV + 135.91	0.62	Igneous, Metamorphic and Sedimentary	Kahraman and Gunaydin (2007)
	LAAV = 2.77SHV + 186.16 (n < 1)	0.60	Igneous, Metamorphic and Sedimentary	Kahraman and Gunaydin (2007)
	LAAV = −1.82SHV + 129.11 (n > 1)	0.72	Igneous, Metamorphic and Sedimentary	Kahraman and Gunaydin (2007)
	LAAV = −9.4572ln(SHV) + 41.075	0.73	Limestones, travertines, marbles, andesite	Ugur et al. (2010)
	LAAV = −53.4861ln(SHV) + 234.3225	0.86	Trachyte, Mafic, Ultramafic	Rigopoulos et al. (2013)
ACV VS PLS (I_S)	ACV = −1.64Is + 36.5	0.54	Granites	Irfan (1994)
	ACV = exp(3.71−0.106Is)	0.90	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
	ACV = 43.08−12.32*Ln(Is)	0.91	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
LAAV VS PLS (I_S)	LAAV = −2.8Is + 56.2	0.51	Granites	Irfan (1994)
	LAAV = exp(3.85−0.087*Is)	0.77	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
	LAAV = 50.35−12.93 * Ln (Is)	0.79	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
	LAAV = $127.96Is^{-0.799}$	0.72	Igneous, Metamorphic and Sedimentary	Kahraman and Gunaydin (2007)
	LAAV = −40.14ln Is + 104.92 (ṅ<1)	0.81	Igneous, Metamorphic and Sedimentary	Kahraman and Gunaydin (2007)
	LAAV = 104:36 $Is^{-0.682}$ (ṅ>1)	0.77	Igneous, Metamorphic and Sedimentary	Kahraman and Gunaydin (2007)
	LAAV = −4.8162ln(Is) + 12.453	0.67	Limestones, travertines, marbles, andesite	Ugur et al. (2010)
AIV VS PLS (I_S)	AIV = exp(3.71−0.115*Is)	0.85	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
	AIV = 42.20−12.41 * Ln (Is)	0.86	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
UCS VS ACV	ACV = exp(3.71−0.005*UCS)	0.86	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
	ACV = 78.82−11.73*Ln (UCS)	0.89	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
UCS VS AIV	AIV = exp(3.72−0.005*UCS)	0.84	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
	AIV = 78.47−11.87*Ln (UCS)	0.87	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
UCS VS LAAV	LAAV = exp(3.85−0.004*UCS)	0.76	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
	LAAV = 88.01−12.35*Ln (UCS)	0.78	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
	LAAV = −24.12Ln(UCS) + 143.78	0.63	Igneous, Metamorphic and Sedimentary	Kahraman and Fener (2007)
	LAAV = −26.23ln(UCS) + 150.81	0.50	Igneous	Kahraman and Fener (2007)
	LAAV = $511.42UCS^{-0.62}$	0.81	Metamorphic	Kahraman and Fener (2007)
	LAAV = $536.89UCS^{-0.60}$	0.50	Sedimentary	Kahraman and Fener (2007)
	LAAV = −3.9076ln(UCS) + 22.666	0.80	Limestones, travertines, marbles, andesite	Ugur et al. (2010)
	LAAV = −20.5197ln(UCS) + 115.7394	0.86	Trachyte, Mafic, Ultramafic	Rigopoulos et al. (2013)

ACV aggregates crushing value, AIV aggregates impact value, LAAV Los Angeles abrasion value, TFV ten percent fines, SHR Schmidt rebound hammer, PLS Point load strength.

Since aggregates are produced from a rock mass or intact rocks, results of tests on such rocks can be correlated with the mechanical properties of the aggregates. The possibility of fast and convenient means to estimate the compressive strength of rocks using index or indirect tests such as Schmidt hammer rebound (SHR) and point load tests have been studied extensively (Al-Harthi, 2001; Çobanoğlu and Çelik, 2008; Fener et al., 2005; Irfan, 1994; Kahraman and Gunaydin, 2009; Ugur et al., 2010). The Schmidt Rebound and point-load tests are quick, require less or no sample preparation and testing methods that can easily be used on the field.

Precambrian basement rocks, which are prevalent in Southwestern Nigeria, form the main source of construction aggregates in Ado-Ekiti, Nigeria. The availability of these Precambrian

Table 2
Published correlations between the different aggregate strength properties.

Relationship	Equations	R^2	Rock types	References
AIV VS ACV	ACV = 3.804 + 0.85226AIV	0.96	Magnesian Limestone, Quartz Dolerite, Olivine Dolerite, Concretionary Dolerite, Granite	Turk and Dearman (1988)
	AIV = 1.1ACV − 2.60	0.65	Granitic Rocks	Irfan (1994)
	ACV = 2.08 + 0.85 AIV	0.72	granite, granodiorite, gneiss amphibole schist and andesite	Harthi and Abo Saada (1997)
	AIV = 0.9ACV − 0.82	0.94	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
	ACV = 0.91AIV + 1.79	0.88	Limestone, marble, granite	Palassi and Danesh (2016)
AIV VS LAAV	AIV = 0.6 LAAV + 3.4	0.66	Granitic Rocks	Irfan (1994)
	LAAV = 3.12 + 0.9 AIV	0.68	granite, granodiorite, gneiss amphibole schist and andesite	Harthi and Abo Saada (1997)
	AIV = 0.82LAAV − 2.10	0.82	Igneous, Metamorphic and Sedimentary	Al-Harthi (2001)
	LAAV = $10.48e^{0.066AIV}$	0.92	Limestone, marble, granite	Palassi and Danesh (2016)
ACV VS LAAV	LAAV = $10.01e^{0.0668ACV}$	0.88	Limestone, marble, granite	Palassi and Danesh (2016)
AIV VS 10% FINES	AIV = −009FV + 39.1		Granitic Rocks	Irfan (1994)
	10% Fines = 373.02−11.35 AIV	0.65	granite, granodiorite, gneiss amphibole schist and andesite	Harthi and Abo Saada (1997)
	10% Fines = 3589.9 * $AIV^{-0.99}$	0.94	Magnesian Limestone, Quartz Dolerite, Olivine Dolerite, Concretionary Dolerite, Granite	Turk and Dearman (1988)
10% FINES VS ACV	10% Fines = 18.51 + 0.048ACV	0.85	Magnesian Limestone	Turk and Dearman (1989)
	10% Fines = 2.255 + 0.067ACV	0.90	Concretionary Limestone	Turk and Dearman (1989)
	10% Fines = 6.15 + 0.0577ACV	0.96	Altered quartz dolerite	Turk and Dearman (1989)
	10% Fines = 0.035ACV − 0.6216	0.94	Quartz Dolerite	Turk and Dearman (1989)
	10% Fines = −1.685 + 0.04ACV	0.98	Olivine Dolerite	Turk and Dearman (1989)
	10% Fines = 5478.55 * $ACV^{-1.11}$	0.85	Magnesian Limestone, Quartz Dolerite, Olivine Dolerite, Concretionary Dolerite, Granite	Turk and Dearman (1989)

ACV aggregates crushing value, AIV aggregates impact value, LAAV Los Angeles abrasion value, TFV ten percent fines, SHR Schmidt rebound hammer, PLS Point load strength.