The International Journal of Engineering and Science (IJES)
|| Volume || 8 || Issue || 4 Series I || Pages || PP 57-64 || 2019 ||
ISSN (e): 2319 – 1813 ISSN (p): 23-19 – 1805

Determination of some mechanical properties of Bushveld Rocks

Oniyide G. O.,
Department of Mining Engineering, Federal University of Technology, Akure, Ondo State, Nigeria.

ABSTRACT:
This paper presents the results of the laboratory experiments carried out on selected rocks from the South African platinum mines, located in the Bushveld Igneous Complex (BIC), for the determination of their physical and mechanical properties. The test specimens were cylindrical core samples from BafokengRasimoni Platinum mine (BRPM), Siphumele platinum mine and Khomanani platinum mine and Mogalakwena Platinum mine. Uniaxial Compressive Strength (UCS) tests were conducted on Siphumelele and Mogalakwena specimens, while Uniaxial Compressive with Modulus (UCM) tests were done on BRPM and Khomanani specimens. The specimen is compressed at a constant loading rate of 0.5 kN/sec. such that failure occurs within 5-10 minutes of loading. It was observed that the UCS of Simphumelele specimens were far less than those from other mines for the same rock types. The tests also revealed that for specimens of the same rock type and size, there is variability in their UCS. This may be attributed to textural or compositional influence. Another important observation is that pyroxenite has the highest values of Young's modulus, shear modulus, tensile strength and least value of Poisson's ratio, which implies that it will be a good hanging wall or footwall material. However, the reverse is the case with chromitite, which has the highest value of Poisson's ratio and lowest values of Young's modulus, shear modulus and tensile strength. Other rock types fall between these extremes.
Keywords: *mechanical properties, rock, Bushveld, platinum mines*

Date of Submission: 26-04-2019 Date of acceptance: 06-05-2019

I. INTRODUCTION

The determination of basic mechanical properties of rocks is important to rock engineering project design. Several mechanical properties, including uniaxial compressive strength (UCS), have become widely accepted parameters for rock design projects [1]. The UCS is undoubtedly the geotechnical property that is most often quoted in rock engineering practice. It is widely understood as a rough index which gives a first approximation of the range of issues that are likely to be encountered in a variety of engineering problems including roof support, pillar design, and excavation technique [2]. Compression tests are intended for classification and characterization of intact rocks. The deformability, strength and failure mode of intact rock are critically important for understanding the basic mechanics of excavation and support requirement. Rock properties, such as, Young's modulus, Poisson's ratio, and strength are derived from unconfined and triaxial compression tests. In addition, shear strength (cohesion and angle of internal friction) are obtained from triaxial compression tests [3].

As [4] noted, the understanding of the characteristics of rock and rock masses, as engineering material, starts with the knowledge of the behaviour of intact rock. The uniaxial compression test is performed by taking a right cylinder of intact rock, loading it along its axis and recording the force and displacement produced as the force is increased. The test can be done with a soft or stiff testing machine. If a soft testing machine (such as Amsler compression testing machine, Figure 1) is used, the post-peak region of the stress-strain curve could not be obtained. However, if done with a stiff testing machine (such as MTS servo-controlled testing machine, a complete stress-strain curve will be obtained, showing the post-peak and residual stress and strains of the specimen.

According to [5], the uniaxial compressive strength can be calculated by dividing the peak load applied to the specimen during the test by the original cross-sectional area. Axial tangential Young's modulus at 50% of uniaxial compressive strength, E_t, was calculated as the slope of tangent line of axial stress-axial strain curve.

Poisson's ratio (v) at 50% of uniaxial compressive strength is calculated as:

$$\nu = \left| -\frac{\text{slope of axial stress vs strain curve}}{\text{slope of lateral stress vs strain curve}} \right| \quad (1)$$

The bulk and the shear moduli were calculated from the formula below:

$$K = Bulk\ Modulus = \frac{E}{3(1-2\nu)} \quad (2)$$

$$G = Shear\ Modulus = \frac{E}{2(1+\nu)} \quad (3)$$

This paper presents the methodology, the equipment/materials for all the laboratory tests conducted on selected rock samples from the South African platinum mines, in addition to the results obtained. The tests include determination of the following properties on the rock samples from the BIC: Mechanical properties (UCS, Young's modulus, Poisson's ratio) under ambient temperature and uniaxial loading using Amsler testing machine. Triaxial loading was also carried using the same testing machine.

II. MATERIALS AND METHODS

2.1 Rock samples and their sources

The rock samples tested were obtained from four different mines located in the northern and the western limb of the BIC. The mines and the samples obtained are summarized in Table 1.

2.2 Specimen preparation

The specimens were prepared according to [6]. The test specimens for uniaxial and triaxial testing were prepared with a height to diameter ratio of 2.5. The ends of the specimen were cut and ground parallel to each other, and at right angle to the longitudinal axis. The disparity between the perpendicular ends of the specimen to its longitudinal axis was not more than 0.05 in 50 mm.

2.3 Compressive strength testing using Amsler testing machine

The uniaxial and triaxial compressive strength of the rock samples were determined under ambient temperature (approximately 20°C) using Amsler compression testing machine, shown in Figure 1. The machine is hydraulic, soft type with a load capacity of 2000 kN. Testing is done manually at a constant rate by controlling force-controlled, which results in violent uncontrolled failure at the peak force. The loading rate is manually controlled. The hydraulic piston, which applies force on test specimens, is located at the base of the load frame.

2.4 Test specimens

The test specimens were cylindrical core samples from BRPM, Siphumele platinum mine and Khomanani platinum mine and Mogalakwena Platinum mine. Uniaxial Compressive Strength (UCS) tests were conducted on Siphumelele and Mogalakwena specimens, while Uniaxial Compressive with Modulus (UCM) tests were done on BRPM and Khomanani specimens. Four strain gauges were glued on the cylindrical specimens, two axially and two transversely, for measurement of axial and lateral strains respectively while the specimen is being loaded. A strain gauge is a device whose electrical resistance varies in proportion to the amount of strain in the device. Lead-wires connected to the strain gauges (Figure 2) transfers signals from the specimen to TLC-strain guage amplifier and then to the computer, where the experimental data are stored. Programme control and data acquisition are achieved with "Lab-VIEW precision data acquisition and control version 8" (Figure 3).

2.5 Test procedure for uniaxial compression test

The specimen is placed in between the lower platen and the spherical seating of the machine. The lead-wires were connected to the bridge box and data logger. The specimen is then compressed at a constant loading rate of 0.5 kN/sec. such that failure occurs within 5-10 minutes of loading as recommended by [5]. The load is measured by the load cell at the base of the lower platen.

Uniaxial compressive strength, Young's modulus and Poisson's ratio were calculated. The aim of performing UCS and determination of elastic properties is for comparison of the strength parameters of the different rock types in ambient condition.

III. RESULTS AND DISCUSSION

Figures 4 and 5 show some of the graphs of stress versus strain for the tested specimens under uniaxial compression.
Table 2 shows the UCS of the rocks, while the bulk modulus, shear modulus, tensile strength and density of the rocks are given in Table 3.

Looking through Table 2, the following observation is worthy of note:

The UCS of Simphumelele specimens were far less than those from other mines for the same rock types. For example, the average UCS of MA, PX are 119, 89 for Simphumelele and 203, 162 for BRPM specimens. This may be attributed to textural or compositional influence. The table also revealed that for specimens of the same rock type and size, there is variability in their UCS. For instance, the average UCS of MA, PX, VTA are 273, 343, 223 and 203, 162, 182 for Mogalakwena and BRPM specimens respectively. Obviously, the Mogalakwena specimens are of higher strength than those of the BRPM. [7] stated that there is variability in the rock type properties of the BIC rocks. The reason of this variability remains unclear. They gave analysis of mottled anorthosite sourced from different stratigraphic horizon at approximately 25 and 50 m in the hangingwall of the Merensky horizon. Analysis of the individual strengths from these horizons indicated the Uniaxial Compressive Strength (UCS) to be 175 and 233 MPa respectively. [8] also observed variability on Poisson's ratio for anorthosite. He reported Poisson's ratio of 0.70 and 0.32 at 50% of the UCS for non-linear and linear samples respectively. [9] proposed some reasons for the variation of strength of norites around the Merensky Reef. These include textural relations and mineral associations, bulk rock composition, the nature and amount of cementing medium, fabric and stress history of the rock from early compaction to late-stage cooling.

Table 3 shows that pyroxenite has the highest values of Young's modulus, shear modulus, tensile strength and least value of Poisson's ratio, which implies that it will be a good hanging wall or footwall material. However, the reverse is the case with chromitite, which has the highest value of Poisson's ratio and lowest values of Young's modulus, shear modulus and tensile strength. Other rock types fall between these extremes.

Triaxial compression strength testing

Only the specimens from BRPM were tested in triaxial compression. Specimen preparation is similar to uniaxial testing, including the length to diameter ratio. Strain gauges were also attached to the specimen for the determination of axial and lateral strains while loading took place by Amsler testing machine.

The confining pressure was applied to the specimen with the aid of a hydraulic pump. The triaxial cell used is Hoek cell (Figure 6) that consists of the cell body, spherical seatings and a flexible membrane which prevents the confining fluid from entering the specimen. The specimens were tested at three confinements, which are, 5 MPa, 10 MPa and 15 MPa. The aim of the triaxial testing is to determine the Mohr-Coulomb parameters of the rocks, that is, cohesion, angle of internal friction and bulk shear modulus at ambient temperature.

After the specimen is placed in the cell, the lead-wires from the strain gauges were connected to the bridge box for recording the strain data. The axial load and the confining pressure were increased simultaneously up to 5 MPa, 10 MPa and 15 MPa for each test individually. Thereafter, the axial loading continued until failure occurred. The specimen was loaded at a constant rate of approximately 0.5 kN/sec, such that failure occurred within 5-10 minutes of loading. The values of the axial load and strains were recorded throughout the test.

The compressive strength is the peak stress sustained by the specimen. The peak stresses were plotted against their corresponding confining pressures. The tangent of the slope, m, of a straight line drawn across the points (Figure) is used in the calculation of the internal friction angle, Ø, and the cohesion, c of the intact rock, as in the equations and shown below. The position of the straight line is fixed by the ordinate, σ_c that stands for the UCS.

Friction Angle, andCohesion,

$$\emptyset = \sin^{-1}\left(\frac{m-1}{m+1}\right) \quad (4)$$

$$C = \left(\frac{1-Sin\emptyset}{2Cos\emptyset}\right)\sigma_c \quad (5)$$

The plot of peak stress versus confining pressure, is given in Figure 7, while Table 4 gives the fitting parameters generated from Figure 7. Table 5 presents the values of the calculated internal angle of friction and cohesion for BRPM specimens.

As observed in Table 5, varitextured anorthosite has the highest value of angle of internal friction, followed by mottled anorthosite, while pyroxenite has the least. Also, mottled anorthosite has the highest value of cohesion followed by varitextured anorthosite, while chromitite has the least

IV. CONCLUSION

This paper presents the result of laboratory tests conducted on selected rock samples from the South African platinum mines. The results show that there is variability in the rock type properties of the BIC. Another important observation is that pyroxenite has the highest values of Young's modulus, shear modulus, tensile strength and least value of Poisson's ratio, which implies that it will be a good hanging wall or footwall material. However, the reverse is the case with chromitite, which has the highest value of Poisson's ratio and lowest values of Young's modulus, shear modulus and tensile strength. Other rock types fall between these extremes.

REFERENCE

[1]. Baskerville CA. Unconfined compressive strength on rock samples representative of the types found in Bronx county, New York. Reston, Virginia: US Geological Survey; 1987, Open-file Report 87-136.

[2]. Hoek E. Rock Mechanics Laboratory Testing in the Context of a Consulting Engineering Organization.Int. J. Rock Mech. Min. Sci. and Geomech, Abstract 14, 1977, pp.93-101.

[3]. Li Y. Wang J. Jung W. and Ghassemi A. Mechanical Properties of Intact Rock and Fractures in Welded Tuff from Newberry Volcano. Proceedings of Thirty-Seventh Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 30 - February 1, 2012.

[4]. Hoek, E., and C. D. Martin. "Fracture initiation and propagation in intact rock–a review." Journal of Rock Mechanics and Geotechnical Engineering 6.4 (2014): 287-300.

[5]. Suggested Methods for determining the Uniaxial Compressive Strength and Deformability of Rock Materials, Commission on Standardization of Laboratory and Field Tests, Int. J. Rock Mech. Min. Sci. &Geomech, 1979, Abstr., 16, 135-140, Reprinted in Rock Characterization, Testing and Monitoring – ISRM Suggested Methods, ed. E.T. Brown, Pergamon, Oxford, (1985) 111-116.

[6]. Suggested method for determining the strength of rock material in triaxial compression: Revised version, Int. J. Rock.Mech. Min. Sci. &Geomech.Abstr. Vol. 20, No. 6, 1983, pp. 283–290.

[7]. Haile, A.T. and Jager, A.J. Rock mass condition, behaviour and seismicity in mines of the Bushveld igneous complex, SIMRAC Report GAP 027, Department of Mineral and Energy Affairs, South Africa, 1995.

[8]. Watson, B.P. Rock behaviour of the Bushveld Merensky Reef and the design of crush pillars, PhD thesis, School. of Mining Engineering, University of Witwatersrand, Johannesburg, RSA, 2010.

[9]. Wilson A.H., Jermy C.A., Ridgeway M and Chunnett G. Rock-Strength and Physical Properties of Norites of the Merensky and Bastard units, Western Bushveld Complex.South African Journal of Geology.Vol. 108,2005pp. 525 -540.

[10]. M.I Alsayed, Utilising the Hoek triaxial cell for multiaxial testing of hollow rock cylinders, International Journal of Rock Mechanics and Mining Sciences, Volume 39, Issue 3, 2002, Pages 355-366, ISSN 1365-1609, https://doi.org/10.1016/S1365-1609(02)00030-8.

Table 1. Details of the samples received from different mines

S/N	Mines	Company	BIC location	Rocks received	Diameter (mm)
1	MogalakwenaPlatinum mine	AngloAmericanPlatinum	Northern limb	VTA, MA, PX	36
2	BafokengRasimone Platinum	Royal Bafokeng Platinum (BRPM)	Western limb	N, LN, ANCR, VTA, MA, CR, PX	36
3	Khomanani Platinum mine	AngloAmerican Platinum	Western limb	GN : gabbro-norite; N, LN, VTA, MA, PX	47*
4	Siphumelele Platinum mine	AngloAmerican Platinum	Western limb	N, LN, MA, PX	32

* N:B- The diameter of the Khomanani samples were reduced to 42 mm in the laboratory before testing.
ANCR : anorthosite-chromitite; CR : chromitite; LN : leuco-norite; MA : mottled-anorthosite; N : norite; PX : pyroxenite; VTA : varitextured-anorthosite;

Table 2. UCS of specimens from Khomanani, Siphumelele, Mogalakwena and BRPM in MPa.

Mines	Specimen	Rock types								
		MA	PX	VTA	N	LN	CR	ANCR	GF	G
Khomanani	1	264	126	314	179					
	2	287	102	238	189					
	3	285	121	276	221					
	4	280	115	325	185					
	5	276	118	247	213					
	Average	**278**	**116**	**280**	**197**					
Siphumelele	1	126	65		55	148				
	2	115	85		73	130				
	3	100	115		75	132				
	4	95	83		80	136				
	5	159	95		90	138				
	Average	**119**	**89**		**75**	**137**				
Mogalakwena	1	292	334	231					274	153
	2	271	361	205					251	205
	3	256	335	234					227	176
	4	336	360	221					266	145

	5	210	327	224					235	180
	Average	**273**	**343**	**223**					**251**	**172**
BRPM	1	201	163	180	151	175	63	150		
	2	208	164	178	155	172	71	130		
	3	208	165	185	160	186	70	135		
	4	204	157	185	143	172	66	125		
	5	193	161	184	159	170	65	133		
	Average	**203**	**162**	**182**	**154**	**175**	**67**	**135**		

Table 3. Strength and physical properties of rocks from BRPM

	ANCR	**CR**	**LN**	**MA**	**N**	**PX**	**VTA**
Bulk Modulus	108.6	128.7	73.4	94.1	65.6	71.9	94.5
Shear Modulus	23.3	17.3	28.4	27.8	23.9	44.6	26.9
Young's Modulus	65.2	49.7	75.4	75.9	63.8	110.9	73.7
Poisson's Ratio	0.40	0.44	0.33	0.37	0.34	0.24	0.37
Tensile Strength	7.2	4.9	9.5	9.5	11.2	11.4	8.9
UCS	135	67	175	203	154	162	182
Density	2853.1	4050.0	2776.4	2744.8	3045.4	3194.0	2766.5

Table 4. Fitting parameters generated from Figure 7

Samples	**Intercept Value**	**Slope Value (m)**	**Statistics Adj. R-Square**
ANCR	131.2803	10.35836	0.9963
CR	68.2159	9.17958	0.97172
LN	174.451	8.8839	0.92361
MA	195.0856	14.49122	0.96633
N	177.207	8.7898	0.91505
PX	164.7673	5.89586	0.99318
VTA	177.5834	14.11938	0.99463

Table 5. Values of m, angle of internal friction and cohesion for BRPM specimens

Parameters	**ANCR**	**CR**	**LN**	**MA**	**N**	**PX**	**VTA**
m	10.36	9.18	8.88	14.49	8.79	5.90	14.12
Ø	55.27	53.13	52.09	59.43	52.75	45.24	59.77
C	32.77	20.69	41.59	51.43	36.40	35.21	44.62

Figure 1.Amsler Compression Testing Machines

Figure 2: Specimens with strain gauges and lead-wires.

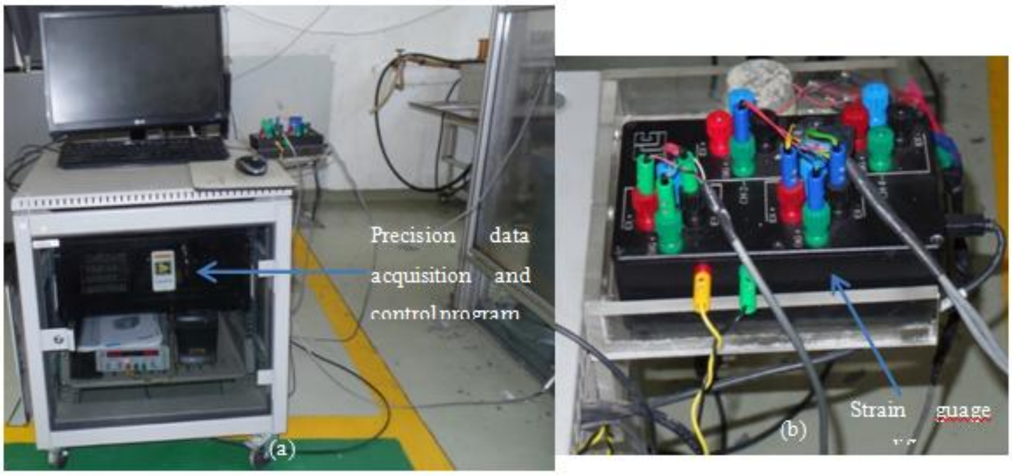


Figure 3: Data acquisition system (a) data acquisition and control unit (b) strain gauge amplifier.

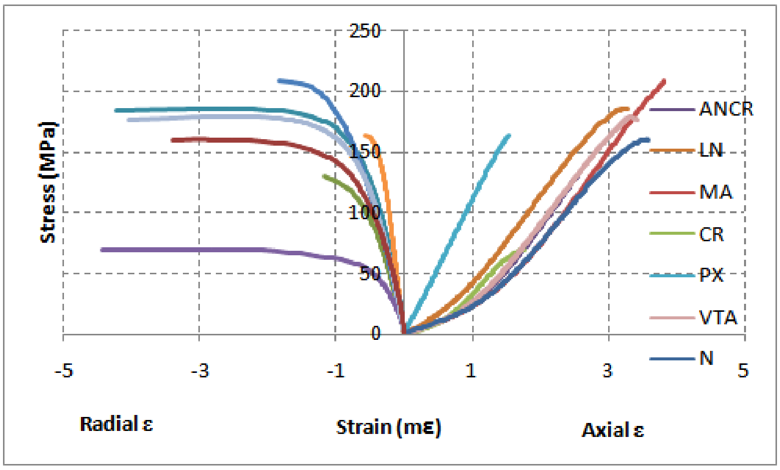


Figure 4. Stress-strain for BRPM specimens

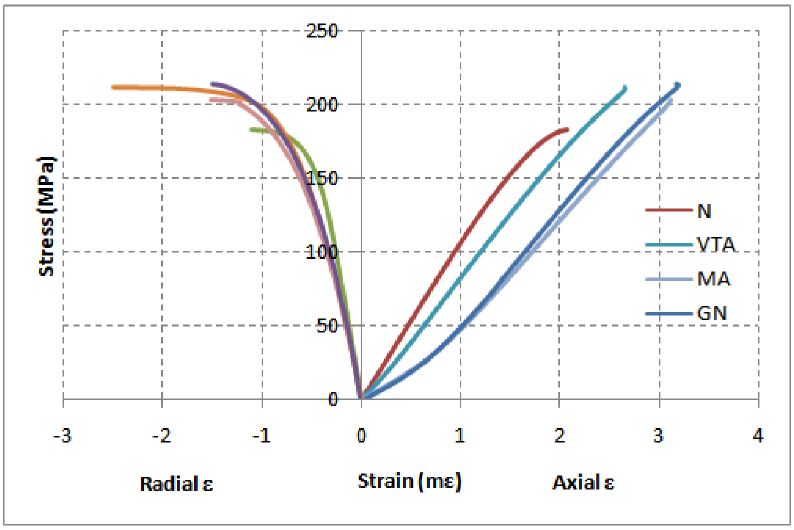
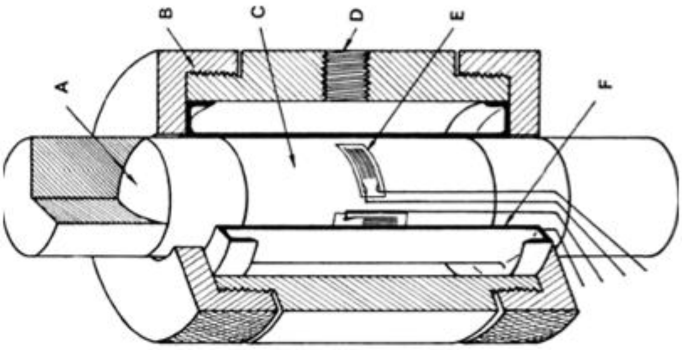


Figure 5: Stress-strain plot for Khomanani specimens



A- Spherical seat, B – Mild steel cell body, C – Rock specimen, D – Oil inlet, E – Strain gauges, F – Sealing membrane

Figure 6: Triaxial cell (After, [10])

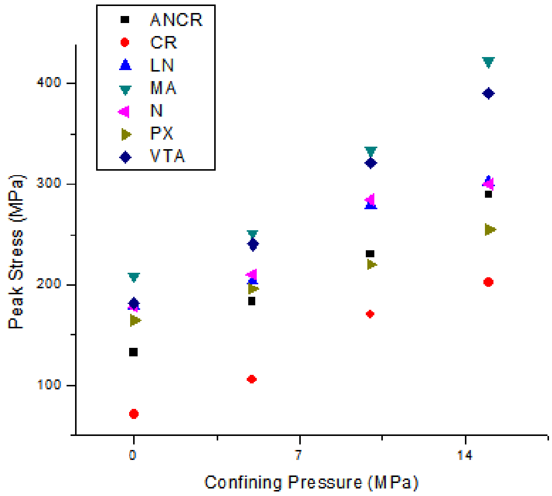


Figure 7: Plot of peak stresses versus confining pressures

Oniyide G. O" Determination of some mechanical properties of Bushveld Rocks"The International Journal of Engineering and Science (IJES), 8.4 (2019): 57-64